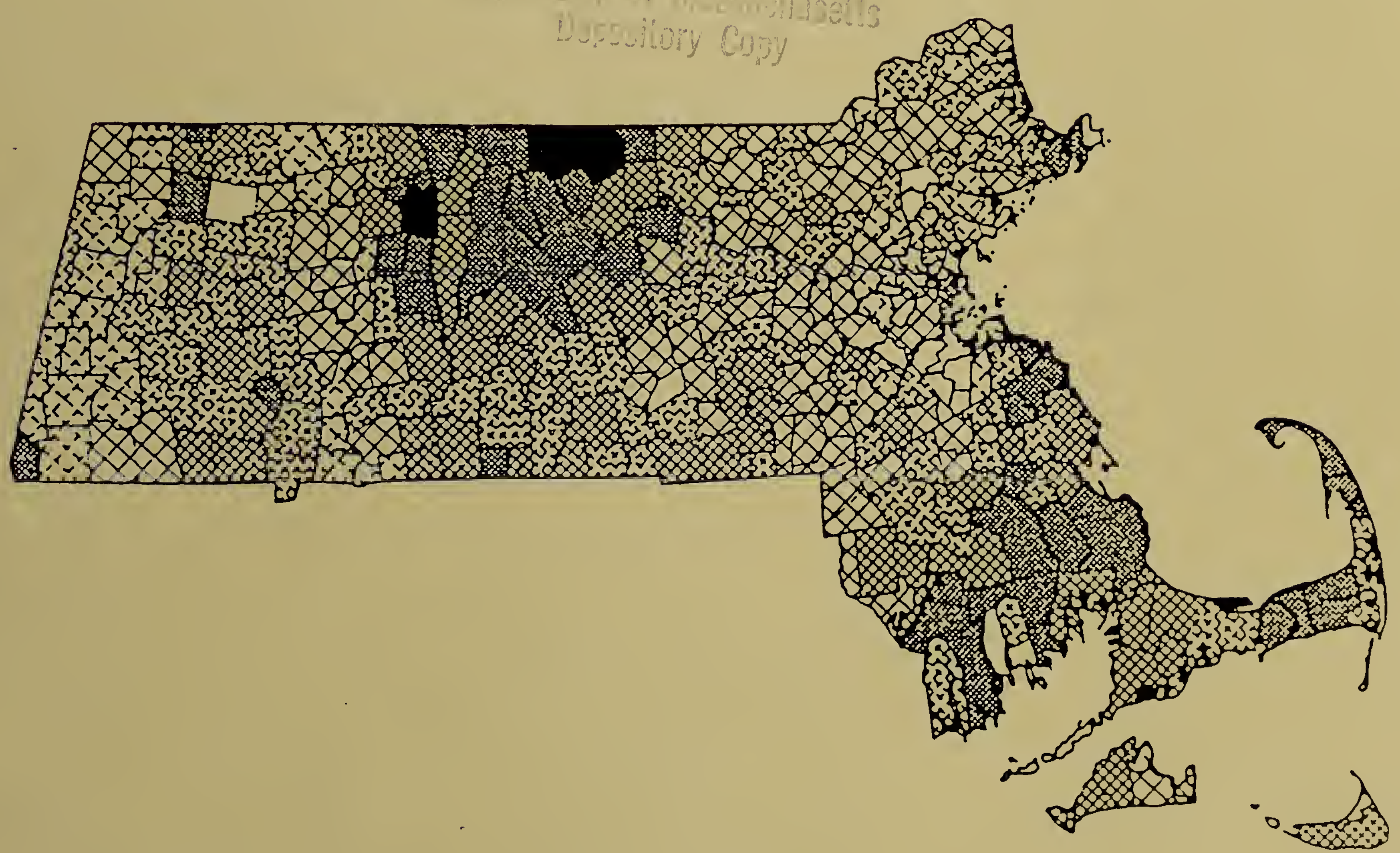
Interim Report on the Findings of the Massachusetts Acid Rain Research Program

June 1988



By

The Massachusetts Executive Office of Environmental Affairs

James S. Hoyte, Secretary
Michael S. Dukakis, Governor

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FORWARD

This interim report is a summary of the research results to date in light of the original policy questions that formed the basis of the Massachusetts Acid Rain Research Program, which was initiated in July 1984. It also contains discussions on the general direction of this research and recommendations for future action.

The data and interpretations referred to in this report were taken from the scientific abstracts and reports generated by the research work of scientists in the state agencies and independent researchers. The abstracts make up Section IV of this report. The full research reports are available to interested persons upon request to the Assistant Secretary for Research and Data Management in the Executive Office of Environmental Affairs (EOEA).

In reading this interim report, it should be recognized that it is the distillation of thousands of pages of material produced by the research teams involved in this program. Represented here are the efforts of a great many people who have participated in the research projects, written summary reports, and assisted in the preparation and editing of this interim report. The Executive Office of Environmental Affairs wishes particularly to thank the members of the Scientific Advisory Council on Acid Rain Research.

Whereas individual people are too numerous to mention, the Executive Office of Environmental Affairs is grateful for their contributions.

This report was developed on the basis of abstracts and reports submitted by researchers and agency staff for each of the 27 projects discussed herein. Most of these abstracts appear essentially as submitted, but a few have been edited and rewritten. In the sections summarizing the researcg findings, the selections and interpretations are the responsibility of the Assistant Secretary for Research and Data Management, EOEA. Responsibility for asny mistakes reside there.

COVER MAP NOTE:

The cover map illustrates the varying degrees of sensitivity to acidification and loss of acid neutralizing capacity of surface waters in Massachusetts towns. The darker or denser the grid design, the greater the sensitivity. Data to construct the map were collected by Acid Rain Monitoring Project volunteers, and the map was produced by A.R.M. staff at the Massachusetts Water Resources Research Center, University of Massachusetts, Amherst.

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EXECUTIVE SUMMARY

Acid rain is a major threat to the quality of life in Massachusetts. Valuable natural and cultural resources, many of which are irreplaceable, are endangered by atmospheric deposition of acids. Solving this critical problem requires the collective, multi-level effort of scientists, political leaders, public agencies, industry and the public. The development of effective solutions requires reliable information from a wide variety of disciplines. The goal of the Massachusetts Acid Rain Research Program (MARRP) has been to develop a sound factual basis for future action.

The necessity for detailed and accurate information regarding damages within Massachusetts and possible cause and effect relationships impelled the state to fund and develop the Massachusetts Acid Rain Research Program. In the spring of 1984, the Governor's Scientific Advisory Council on Acid Rain Research recommended an initial research effort for the purpose of gathering necessary baseline data, to be followed by a longer research program aimed at more complicated cause and effect issues, and a well-designed long term monitoring program which would extend into the indefinite future. The state program is now in the process of shifting between these two stages.

For each of the past four fiscal years the Executive Office of Environmental Affairs has received $500,000 for the Massachusetts Acid Rain Research Program (MARRP). That money has been supplemented by a line item in the DFWELE budget in support of the Cooperative Aquatic Research Program, which includes the Acid Rain Monitoring Project (ARM) at UMass/Amherst and several other related projects, as well as internal research projects conducted by DFWELE. This state funding also has been supplemented by funds from several federal agencies. Ongoing efforts are made to coordinate between MARRP and federal research programs.

The Program has included research into the effects of acid rain on atmospheric, aquatic, terrestrial and cultural/historical resources within the Commonwealth, and has attempted to assess the potential impacts of acid rain upon human health. Results to date indicate that:

(1) Precipitation in Massachusetts is highly acidic with an average pH of 4.2. Higher concentrations of sulfur dioxide and nitrogen dioxide have been associated with winds from the southwest as have reduced visibility and higher concentrations of particulates. These data continue to confirm that long-range transport from sources of emissions located to the south and west of Massachusetts is a major source of pollution in Massachusetts and New England. Regional haze resulting from sulfate particulates in the air has caused a 50% decline in visibility in rural New England since the 1950's. It has been estimated that reducing this regional haze by as little as 13% could result in as much as 126 million additional dollars generated through tourism. Atmospheric sulfate and nitrate pollution in Massachusetts has been related to hospitalization for cardiovascular and lung ailments.

(2) The vast majority of lakes and streams in Massachusetts are highly sensitive to acidification. Even with constant or slightly declining levels of acid deposition, acidification of surface waters is likely to continue.

Quabbin Reservoir has lost 75% of its acid neutralizing capacity in the past 40 years, and in recent years has experienced dramatic declines in fish populations. Increased mobilization of metals in acid impacted watersheds and their subsequent bioaccumulation in fish and wildlife may be one of the most serious consequences of acid rain and related air pollutants. The corrosive nature (aggressiveness) of the state's drinking water supplies necessitates significant annual expenditures for pH treatment to minimize dissolution of metals from distribution pipes.

(3) Preliminary results from studies of Norway spruce, red spruce, and sugar maple clearly establish that forest decline is a significant problem for sensitive species in some areas of Massachusetts. Mortality rates are high in the red spruce forest, and sugar maples display a variety of decline symptoms. We need to be concerned that if acid deposition continues at its current level, the injury threshold for many more tree species will be exceeded. If this occurs and forest productivity in the Commonwealth is significantlky reduced, it could have a costly impact on the wood products industry, recreational opportunity, wildlife habitats and watershed protection.

(4) Acid deposition can cause etching and erosion of culturally important monuments and buildings. Bronze and marble statues, tombstones and marble building facades are being destroyed throughout the state by atmospheric acidity. Annual replacement costs for bare galvanized steel destroyed by acid deposition or sulfur dioxide in Boston are estimated at over $33 million per year; damage to paint is estimated at $31 million per year. Costly protective coatings for metals must be regularly maintained to prevent further disfigurement. To protect only the most important bronze statues in Massachusetts would cost between two to six million dollars over a ten year period. Protective materials do not exist for stone materials. Once stone materials start to deteriorate from acid etching, repeated freezing and thawing accelerate the process.

The Massachusetts Acid Rain Research Program clearly has produced a wealth of important benefits and insights. While research done in Massachusetts and elsewhere continues to document serious environmental deterioration in the face of this problem, this same research has shown that the problem is more complex than was first thought. **There exists, therefore, a strong need to increase our efforts towards understanding and resolving the problem at all levels. It is clear that acid rain is a serious problem; we must address it by reducing pollutant emissions as well as by conducting further research.** The major means by which the Commonwealth can accomplish these tasks are:

> Proceeding with emission controls within the Commonwealth, focusing initially on existing SO_2 control legislation, but eventually considering controls for NO_x and related oxidants.

> Continuing acid rain research within the Commonwealth, based on the needs identified by research conducted previously, and continuing efforts at public education.

> Continuing efforts to achieve responsible action at the national level.

To date, elected and appointed officials within the Commonwealth have employed a multi-faceted approach which has included a variety of measures designed to limit acid rain damage within the Commonwealth as well as regional or national measures designed to assist other states or the federal government in reducing acid rain. This report recommends that a broad-based, multi-level approach be continued as the most effective means of achieving reductions in the impacts of acid rain upon Massachusetts.

Despite the existence of uncertainty about many potential effects of acid deposition, most researchers feel that sufficient information exists to define the threat, and that the risks of environmental damage justify controlling emissions based on existing knowledge. The challenge for policy makers is to design environmental regulations that will restore and protect the environment, minimize economic costs and social dislocations and still retain sufficient flexibility to be adjusted as additional information becomes available. This will be accomplished only when acid deposition and related air pollutants have been reduced to the level where they no longer cause damage to our natural and cultural resources and public health.

In 1985 the Massachusetts legislature passed legislation (Chapter 590) limiting SO_2 emissions from sources within the Commonwealth. This law includes two main components; the first is a "cap" on statewide SO_2 emissions based on the annual average from the period 1979 to 1982. The DEQE must ensure that levels of SO_2 emitted from all anthropogenic sources combined do not exceed the average annual level from that period. The DEQE has been implementing this program since 1986. To date, annual total SO_2 emissions have remained safely below the cap.

The second component of the legislation calls for the DEQE to establish regulations limiting SO_2 emissions from all major sources to 1.2 pounds of SO_2 per million BTU's of fuel input, provided that no national or comprehensive regional acid rain legislation was enacted by the end of 1987. As no such national or regional legislation was adopted, the DEQE is now proceeding with the development of these regulations. The regulations will be implemented in phases by the end of 1995.

The legislature should in the future consider legislation to control or limit NO_x emissions within the Commonwealth, based on the results of the NO_x investigations to be conducted by DEQE, as well as legislation requiring that the least polluting alternative be considered in public issues such as setting of electricity rates and transportation planning.

Ultimately the economic well-being of the Commonwealth depends upon both its environmental quality and an adequate supply of energy. Because air pollutants, including those contributing to acid rain, are closely related to other issues such as electricity generation and transportation, decisions regarding such issues should include consideration of the cumulative effects such decisions are likely to have on acid rain and other forms of air pollution within the Commonwealth. It is recommended that the legislature require that agencies and commissions responsible for such decisions consider the least polluting alternative as an integral part of the decision making process. Mandatory consideration of the air pollution consequences of various options, in addition to cost, will help the Commonwealth's environmental quality keep pace

with its economic growth. Increased interagency coordination, particularly between state environmental and energy agencies, will facilitate this. Given the potential conflicts that can develop between the policies and concerns of energy and environmental agencies, it may be important to provide a formal means of authoritatively resolving interagency issues within state government.

The Massachusetts Acid Rain Research Program, the Massachusetts Acid Rain Monitoring Project (ARM), the "Call for Action" issued by DEQE in 1984, and related state research efforts have been highly effective in informing public officials and educating the public about the threat of acid rain to the Commonwealth's natural and cultural resources. The information produced by this research has provided substantial evidence to support the contention that acid rain is a serious threat in Massachusetts, and has enhanced the Commonwealth's efforts to call for reductions in acid rain at the national level. Specific efforts at public education, such as the booklet Acid Rain in Massachusetts: The Massachusetts Acid Rain Research Program in Action, being produced concurrently with this report, can be an effective means of disseminating research results to the public. In addition, the Commonwealth's investments in acid rain research have proven to be effective in attracting federal funds for related projects.

Many questions remain to be answered, however. It is strongly recommended that research continue in several different areas. Future research must strive to accomplish two objectives: 1) continue to evaluate the impacts of acid deposition and propose equitable solutions, and 2) assuming eventual emissions reductions within the state or elsewhere, monitor and study environmental recovery in order to adjust regulatory policy to optimize environmental protection and minimize social costs. As a result of MARRP and other efforts, the Commonwealth currently participates fully in seeking the best solution to this major environmental problem. This participation should continue.

It is recommended that the Massachusetts Acid Rain Research Program continue as a distinct program coordinated through the Executive Office of Environmental Affairs. Given that, once enacted, any federal acid rain legislation is likely to involve a ten year period before emission reductions become effective, it is recommended that a long term source of funding for the Program be established. This program has proven to be an effective means of accomplishing a wide range of different research objectives through the use of researchers drawn from colleges, universities, private firms and state agencies throughout the state. Such personnel and technical resources for research are abundant in Massachusetts. The information produced by this research can provide evidence relevant to current policy issues as well as help define cost effective implementation measures for control strategies.

The Acid Rain Monitoring Project should continue to be funded within the Cooperative Aquatic Research Program (CARP), which is administered through the Division of Fisheries and Wildlife, and listed as a separate line item in the state budget. This program has been a highly cost effective means of accomplishing research in the area of acid rain effects on aquatic systems.

The new EOEA Office of Research, Testing and Standards should consider establishing an Air Pollution Research and Demonstration Program within the DEQE. Such a program, which would include new funded state employee positions, would provide an on-going means of addressing air pollution questions

in a comprehensive, well integrated way. This program would complement the existing Acid Rain Research Program, which uses contract researchers and focuses exclusively on the acid rain issue. The program would take an overview of air pollution research and demonstration needs and evaluate the results of research from a variety of sources, including the Acid Rain Research Program.

It is generally agreed that any effective acid rain control strategy must involve national legislation and must be applied on a regional or national scale. This is true because of the wide distribution of emission sources and the broad geographic regions over which acidic pollutants are transported and deposited. For this reason, it is important that Massachusetts officials continue to press for national acid rain control legislation in a number of different ways.

It is also recommended that the Commonwealth support, however possible, federally funded research and development of clean coal technology. By providing a means of efficiently converting coal to energy, this technology could help keep coal miners employed, while simultaneously reducing SO_2 and NO_x emissions. The Commonwealth should aggressively assist industry in obtaining federal funding for development and demonstration of this technology.

Increased efforts to integrate Massachusetts research with regional and national research programs should be supported. The benefits of the Massachusetts research and regulatory programs should be shared with the national congress and federal agencies. The Massachusetts comprehensive air quality/acid deposition monitoring sites provides New England and the national acid deposition program with valuable data, but additional staff is needed to assist in integrating state and federal research. It is recommended that this monitoring program be expanded and fully staffed with additional personnel. It also is recommended that a staff position be funded to act as liaison between state and federal agencies.

I: INTRODUCTION

THE CONTEXT

Massachusetts is a densely populated state with abundant resources in the form of surface waters, forests and agricultural lands as well as architecture and monuments that preserve the heritage of our nation's founding. Presently, these valuable resources, many of which are irreplaceable, are endangered by acidic deposition, which has become a critical problem for the Commonwealth.

Although the impacts of acid deposition in Massachusetts were not observed until the late 1970's, Massachusetts has been contributing to the cumulative loss of acid neutralizing capacity (ANC) in its environment over the past several decades. In-state emissions have been reduced by 41% to levels where Massachusetts industry, utilities and transportation sectors generate emissions that account for only 10-30% of the acid deposition in the state. In spite of these dramatic reductions in its own emissions, Massachusetts is still contributing an additional amount to acid deposition in an indirect way by continuing to be a major importer of electricity from other states and by using the products of industries that are major emitters.

Acid deposition is a major threat to the quality of life in the Commonwealth. Solving this problem requires the collective, multi-level effort of scientists, political leaders, public agencies, business and the public. Effective solutions, however, cannot be found in the absence of factual information. Obtaining factual information is the task of researchers, and the goal of the Massachusetts Acid Rain Research Program (MARRP) has been to develop a sound factual basis for future action.

Thus the research must accomplish two objectives: 1) continue to evaluate the impacts of acid deposition and propose equitable solutions, and 2) assuming eventual emissions reduction within the state or elsewhere, monitor and study the course of recovery so that regulatory policy can be adjusted to optimize environmental protection and minimize social costs. As a result of MARRP, the Commonwealth is well situated to participate fully in seeking the best solution to this major environmental crisis.

Despite the existence of uncertainty about some potential effects of acid deposition, most researchers feel that more than sufficient information exists to define the threat, and that risks more than justify controlling emissions based on existing knowledge. The challenge for policy makers is to design environmental regulations that will restore and protect the environment, minimize economic costs and dislocations and still retain sufficient flexibility to be adjusted as additional information becomes available. This task will be completed only when acid deposition and related air pollutants have been reduced to the level where they no longer cause damage to our natural and cultural resources and public health. This is, after all, the goal of the Massachusetts Acid Rain Research Program.

THE RESEARCH PROGRAM

In 1980 Congress authorized the National Acid Precipitation Assessment Program (NAPAP) under the Acid Precipitation Act (P.L. 96-294, Title VII) which directed that a comprehensive federal research plan be developed and implemented over the decade 1980-90. Although research sponsored by NAPAP has produced over 1000 publications to date, the federal effort could not cover every aspect of the acid deposition problem. It became necessary for the states to generate their own complementary research programs that would be tailored to their own particular concerns and would be conducted at a level of detail much greater than that which the broader based federal program could realistically undertake.

Massachusetts is one of the states that decided to undertake its own research program on acidic deposition specific to its own problems. Of primary concern was the need to measure and assess damages to the state's natural and cultural resources at a very detailed level. Since Massachusetts has so much at stake in its rich natural and historical heritage, it could not merely "stand on the side line" in research efforts. The necessity for very detailed and accurate information regarding damages within Massachusetts itself, along with possible causal relationships, impelled the state to fund and develop the Massachusetts Acid Rain Research Program (MARRP).

In July of 1984 the Commonwealth of Massachusetts embarked upon a coordinated research effort directed toward answering several pressing questions concerning the effects of acid deposition on its natural and cultural resources. Prior to that time the state was forced to rely on several independent research efforts and on federal initiatives to answer questions related to acid deposition impacts and to formulate reasoned policy positions.

Those early research projects included the ongoing Acid Rain Monitoring Project (ARM) (plus several other studies) sponsored by the Water Resources Research Center at the University of Massachusetts at Amherst. Early contributions from the state agencies included internal research conducted by the state Division of Fisheries and Wildlife, studies concerning Quabbin Reservoir conducted by the MDC, and the report " Acid Rain and Related Air Pollutant Damage - A National and International Call for Action" issued by DEQE in 1984.

In the spring of 1984 the Governor's Scientific Advisory Council on Acid Rain Research recommended an initial research effort for the purpose of gathering necessary baseline data to be followed by a longer research program aimed at more complicated cause and effects issues and a well-designed monitoring program which would extend into the indefinite future. The state program is now in the process of shifting between stages one and two as mentioned above.

THE POLICY QUESTIONS

The initial policy questions which formed the basis of the research program are discussed fully in the companion document Acid Rain in Massachusetts: The Massachusetts Acid Rain Research Program in Action.

In brief those questions included the following:

What are the Origins, Sources and Magnitudes of SOx and NOx Emissions Impacting Massachusetts?

How much Wet and Dry Deposition is Falling upon Massachusetts?

What are the Impacts of Acid Deposition upon Aquatic Ecosystems in Massachusetts?

What are the Impacts of Acid Deposition upon Forests and other Terrestrial Ecosystems in Massachusetts?

What are the Impacts of Air Pollutants that Cause Acid Deposition upon Public Health through Water and Air Quality?

What are the Impacts of Acid Deposition upon Human Structural and Cultural Resources in Massachusetts?

What Trends can we Detect that are the Result of Acid Deposition?

What Environmental, Sociological and Political Strategies are Available to Mitigate Acid Deposition Effects in Massachusetts?

Why the Continuing Need for Long-term Research?

THE RESEARCH PROJECTS

This report discusses the results of 27 separate research projects funded in part by the line items in the annual appropriation budgets of EOEA and DFWELE. Each of the five environmental agencies is involved in the research program. The 27 projects can be placed in four different categories: Aquatic Effects (15); Terrestrial Effects (5); Acid Deposition Monitoring (4); Public Health and Cultural Effects (3).

One half of these projects are now completed or are expected to be completed within the next 6-9 months. The other half are projects of an on-going nature such as the Acid Rain Monitoring Project, the Forest Stress Analysis Project and the Air Quality Monitoring Project. These projects require at least 10 years of continuous funding in order to track long-term effects and trends, and eventually gage the effectiveness of state and national emission control programs.

The majority of research projects were developed in order to measure and assess damages occurring in the Massachusetts environment. Several projects are concerned primarily with the potential to mitigate those damages through liming of aquatic resources or coating statues and monuments. Some projects are concerned mainly with providing baseline data on air pollutants and acidic deposition against which environmental and cultural effects can be measured, and the effectiveness of emission controls can be gaged.

The next two pages include a list of the 27 research projects discussed in this report.

THE TWENTY-SEVEN (27) RESEARCH PROJECTS

AQUATIC EFFECTS

WATER QUALITY MONITORING

The Acid Rain Monitoring Project (ARM) Phase III - DFWELE

Effects of Atmospheric Wet Deposition on Water Quality in Two Streams - MDC

Hydrologic Controls on the Chemical Response of Streams to Precipitation Events in Central Massachusetts: Implication for Aluminum Mobility - DFWELE

Stimulation of Mercury Methylation by Acid Deposition - DFWELE

Role of Sulfate Reduction in Mitigating the Effects of Acid Deposition in Lakes - DFWELE

BIOLOGICAL EFFECTS

Acidification and Fish Harvest Trends at Quabbin Reservoir - DFWELE

Physiological Stress Indicators in Fishes and their Potential for Application in Field Studies - DFWELE

Reproductive Failure due to Environmental pH and Ionic Factors in Landlocked Rainbow Smelt (Osmerus mordax) - DFWELE

Effects of Acid Precipitation and Breeding Strategies on Salamandar Communities in Massachusetts - DFWELE

MITIGATION

Mitigative Lake Liming - DFWELE

Physical, Chemical and Biological Impacts of Liming on a Cape Cod Kettle Pond DFWELE

Ecological and Chemical Responses of Whetstone Brook during Continuous Treatment with Calcium Carbonate - DFWELE

A Preliminary Economic Assessment of Liming Acidified Lakes and Ponds in Massachusetts - DFWELE

Investigation of Forest Management Impacts on Watershed Hydrology and Aquatic Chemistry - MDC

Biological Monitoring Program, Dickey Brook Watershed, Quabbin Reservoir, 1985-1986 - MDC

TERRESTRIAL EFFECTS

FORESTS

Forest Stress Analysis - DEM

Growth of Massachusetts Forests in Relation to Potential Effects from Acid Deposition - DEM

AGRICULTURE

Predicting Species Tolerance in Nursery Crops to Acid Precipitation/Gaseous Air Pollutant Complex using Pollen Screen - DFA

The Acid Rain-Ozone Pollution Complex and Reproductive Processing in Crop Plants - DFA

Acid Precipitation and Physiological Action of Crop Growth Regulators, Herbicides and Crop Protectants - DFA

ACID DEPOSITION MONITORING

Quabbin Summit Air Quality Monitoring Project - DEQE

Ozone Monitoring at Mt. Greylock - DEQE

Wet Deposition Chemistry and Air Quality Data Analysis Project - DEQE

Acid Deposition Mesoscale Modeling Study - DEQE

PUBLIC HEALTH AND CULTURAL EFFECTS

Massachusetts Pollution Standard Index (PSI) for Air Pollutants - DEQE

Design of a Drinking Water Quality Monitoring Program - DEQE

Effects of Acidic Deposition on Cultural and Historic Resources in Massachusetts - DEQE

FUNDING

For each of the past four fiscal years the Executive Office of Environmental Affairs has received $500,000 for the Massachusetts Acid Rain Research Program. That money has been supplemented by a line item in the DFWELE budget in support of the Cooperative Aquatic Research Program, which includes the Acid Rain Monitoring Project at UMass/Amherst and several related projects, as well as the Division's own internal research projects.

This state funding has been supplemented by funds from several federal agencies. The U.S. Geological Survey (USGS) has been the largest contributor through its state/federal cooperative research program by granting matching federal funds to MDC and DEQE, both of which have committed substantial funds to acid deposition research. Through its Water Resources Institute Program, USGS supports part of the research program of the Water Resources Research Center at UMass/Amherst. DEQE and DFWELE have also received some federal funding for specific projects. The DEQE federal funding runs out, however, at the end of this federal fiscal year.

The U.S. Environmental Protection Agency (EPA) has also contributed funding to DEQE through the State Acid Rain (STAR) program and to DEM through the NAPAP Forest Response Program. DEM has also received funding from the USDA Forest Service. The U.S. Fish and Wildlife Service has assisted DFWELE with funding for stream mitigation research. Ongoing efforts are made to avoid duplication between MARRP and federal research. A vital link between the state and federal research programs is the number of Massachusetts researchers that are involved in review teams for the various NAPAP research areas.

Quality Control and Assurance (QC/QA)

Oversight of the entire Massachusetts research program is provided by the Scientific Advisory Council on Acid Rain Research, which is a group of approximately 25 scientists and senior policy managers representing state, regional and federal agencies, and many universities and colleges. The SAC is chaired by the EOEA Assistant Secretary for Research.

Each state agency is required by EOEA to have a scientific peer review process to assist the agency in planning and reviewing research. These groups may be project specific or program wide, but they are expected to meet at least once per year. Additional scientific peer review occurs as a result of publications that emerge from the Massachusetts research program.

The process of close cooperation between agency personnel and active researchers, and the use of research expertise at academic institutions, state agencies and consulting firms has been particularly effective.

Before discussing the present results of MARRP and the various impacts of acidic deposition in Massachusetts, a brief description of acidic deposition itself is necessary.

ACIDIC DEPOSITION

An acid is a substance that is made up of one or more positively charged hydrogen ions (H^+) and a negatively charged anion, (which is usually a single element such as carbon (C), nitrogen (N) or sulfur (S) combined with several oxygens). The three acids most involved with acid precipitation are sulfuric acid ($H2SO_4$), nitric acid (HNO_3) and carbonic acid (H_2CO_3). Sulfuric and nitric acids are strong acids because they completely dissociate in water and thereby release all of their hydrogen ions and anions into solution. This means that all of these ions are available for physiochemical reactions or biogenic processes. Carbonic acid, on the other hand, is a weak acid because it does not completely dissociate in water and thus its ions are not all available for reactions. Therefore, sulfuric and nitric acids have a much greater acidifying effect than carbonic acid because these two strong acids provide more hydrogen ions in solution.

Acidity may be measured by the concentration of hydrogen ions in solution in units such as mg/l. Because, however, these concentrations range over several orders of magnitude, a more convenient scale called pH was devised. pH is the logarithmic concentration of hydrogen ions in water. The pH scale ranges from 1.0 to 14.0. Pure water is neutral (i.e., equal concentrations of H+ and OH-) and has a pH of 7.0, right in the middle of the scale. All values of <u>pH $\leq$7.0</u> are <u>acidic</u> and have excess hydrogen ions (H+) in solution, whereas all values of pH >7.0 are alkaline and have excess hydroxyl ions (OH-) in solution. Therefore, <u>lower pH</u> means <u>greater acidity</u>, and conversely, higher pH means lower acidity (greater alkalinity). It is important to note that a <u>decrease</u> of <u>pH</u> by <u>1.0</u> unit means a <u>ten-fold increase</u> in <u>acidity</u>. For example, water with pH 5.0 is 10 times more acidic than water with pH 6.0; pH 4.0 is 100 times more acidic than pH 6.0; pH 1.0 (the extreme case) is 100,000 times more acidic than pH 6.0.

Uncontaminated rain with pH 5.0 to 5.6 is already slightly acidic primarily because in the atmosphere naturally occurring carbon dioxide (CO_2) dissolves in rain water to form a very weak solution of carbonic acid. "Acid rain" is defined as rain with an average annual pH <5.0. Typical rain with pH 5.0 has been found even in remote pristine areas of the temperate latitudes. Individual rains may be higher or lower than the annual average, depending on local pollution, weather or season. The average annual pH of precipitation in Massachusetts is near 4.2, which is approximately six times more acidic than uncontaminated precipitation. Acid levels vary seasonally and can be two to five times more acidic in summer than in winter. Acid rain occurs in the United States largely because of the addition of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) as atmospheric pollutants from industrial processes, combustion and mobile sources. These oxides are transformed to sulfuric and nitric acids by complex atmospheric processes.

On average, clouds, fogs and mists are much more acidic than rain in the same area and time. The bottoms of clouds are their most acidic part. Where clouds contact the ground, as on mountain tops or coastal regions, collected moisture is often a pH unit lower, or ten times more acidic, than values from the same clouds rain. Mountain clouds along the Appalachian chain have an average pH of about 3.6, compared to 4.2 for rain. The acidity also varies from cloud to cloud and season to season. The most acid cloud measured in

1986 on Whiteface Mountain, New York had a pH of 2.5. The most acid fog on record (pH 1.7) occurred in the Los Angeles basin.

Acidity can be neutralized by any ion that removes the positively charged hydrogen ion from solution, usually by combining with it to make a new compound. In most natural systems, alkaline compounds such as calcium carbonate (limestone) produce this acid neutralizing capacity (ANC) as part of the weathering process of rocks and soils. ANC exists to varying degrees in organisms, soils, rocks and water in the environment. Without ANC, any acid added to part of the environment would cause an immediate change in pH (i.e., acidity). Thus ANC buffers the system against changes in pH and is crucial to protecting the environment against acidification. It is, therefore, one of the best measures of the sensitivity of environments to acid inputs. At pH 5.0 the ANC of most waters is exhausted. Surface waters in this condition are considered acidified.

There are three main stages in acidic deposition: emission of <u>precursors</u> at the source; <u>transformation</u> <u>and</u> <u>transportation</u> in the atmosphere; <u>deposition</u> at receptor sites.

PRECURSORS

When fossil fuels, primarily coal, oil and gasoline, are burned they emit precursors that are chemically transformed to acids in the atmosphere. Sulfur dioxide, nitrogen oxides and volatile organic compounds (VOC) are the three main groups of chemical precursors involved in producing the acids that are later redeposited on earth. Sulfuric acid is formed by the aqueous-phase or gas-phase oxidation of sulfur dioxide in several ways: by either ozone or hydrogen peroxide in clouds; by hydroxyl radicals (OH^-) in the air; or by catalysts in water films formed on surfaces. Nitric acid comes largely from the gas-phase oxidation of nitrogen dioxide with hydroxyl radicals, which are generated by photochemical reactions involving VOC and sunlight. Hydrogen peroxide (H_2O_2) and ozone (O_3) are also generated by photochemical reactions in the atmosphere involving nitrogen oxides and VOC.

TRANSFORMATION AND TRANSPORTATION

Atmospheric transport and transformation processes provide the links between the emission of air pollutants from the source areas into the atmosphere and later deposition in receptor areas. Many different aqueous-phase and gas-phase reactions occur in the atmosphere between the precursors and various oxidants and other chemical entities, which are often formed from photolysis. Air pollution transformation to acids requires appropriate conditions of temperature, moisture, light and chemical catalysts.

In recent years it has been recognized that the chemical reactions between sulfur oxides, nitrogen oxides, VOC, oxidants and other natural and man-made substances are very complex. Yet an understanding of these complex atmospheric processes is critical to understanding acid formation and deposition. Ozone, hydrogen peroxide, the hydroxyl radical and other oxidants

have been found to be the most important substances responsible for the transformation of sulfur dioxide and nitrogen oxides to acids.

In addition to reactions in air, chemical reactions also take place in clouds, which form around fine particles and subsequently scavenge gases and particles that are transformed through aqueous-phase chemistry within the individual cloud droplets. Scavenging involves primarily the incorporation of particles and gases in cloud droplets, but additional material may also be absorbed during precipitation.

Transport and dispersion of are also important atmospheric processes. The physical movement of pollutants by the winds plays a critical role in how much and in what form a given material reaches sensitive receptor areas. Strong, fast-moving storm systems and slow-moving weak anticyclones are the two contrasting weather types that transport pollutants regionally. There are three main storm tracks into the Northeast: northward up the Atlantic coast; southeastward across Canada; and northeastward out of the Midwest. The prevailing winds in North America are from west to east, which means that New England, including Massachusetts, is right on the major pathways of pollutants being generated and transported eastward.

Summer transport and dispersion patterns are different from those that occur in winter. The large differences observed between summer and winter acidic deposition are due to differences in air chemistry, reaction rates and meteorological conditions. During periods of air stagnation, which are more common in summer and fall, air pollution levels build up and chemical reactions proceed until the polluted air either moves from the area or is cleansed by wet or dry deposition.

ACIDIC DEPOSITION

"Acidic deposition" is a more comprehensive term than "acid rain" because acidity derived from anthropogenic sources has other components besides rain. These components are divided into two categories: wet deposition and dry deposition. Wet deposition includes: acidic rain, snow, sleet, mist and fog; dry deposition includes: the dry forms of sulfate and nitrate particles or gases of sulfur dioxide and nitrogen oxides. Pollutants may be transported great distances along a storm's path until they fall as wet deposition, whereas the quantity of dry deposition declines steeply as the distance from the source increases.

Dry deposition of pollutants is critical in describing total acidic deposition. Dry deposition is particularly complex because it involves both gases and particles and their capture by many different surfaces. This important deposition process transfers atmospheric pollutants to local surfaces and contributes significantly (30-50%) to overall acidic deposition. Although dry deposition is a much less intense delivery mechanism than wet deposition, it operates almost all the time.

Once the wet and dry forms of acidic pollutants have been deposited, they start to break down into various components. Of most concern are sulfuric and nitric acids, which dissociate in water into hydrogen ions and sulfate and nitrate ions. The dissociation of these two strong acids results in increased

acidification with its many effects on aquatic and terrestrial ecosystems, plus various plant and animal life forms, including humans.

Concern about acidic deposition has focused narrowly on sulfur dioxide and nitrogen oxides. However, oxidants such as ozone, hydrogen peroxide and organic free radicals are intimately associated with and required for the production of the sulfuric and nitric acids that cause acidic precipitation. Ozone damage to tree species has been well documented for some time, and H_2O_2 damage at ambient levels has also been demonstrated under controlled conditions in Germany, but not yet in this country. In any effects assessment the <u>combined</u> effect of numerous pollutants must be considered, rather than the separate effects of individual pollutants. Given what is known about the chemical interdependence of the acidic and oxidant pollutants, it may not even be relevant biologically to try and distinguish effects.

II. A SUMMARY OF RESULTS AND HYPOTHESES

This Section of the report presents brief summaries of research results and working hypotheses of the Massachusetts Acid Rain Research Program. The findings summarized in this section represent approximately three years of research efforts, since this report was started in the second quarter of fiscal year 1988. Expenditures over that period of time totaled just less than $2.5 million between the line items in the Executive Office of Environmental Affairs and the Division of Fisheries and Wildlife. By comparison, Federal expenditures for acid rain research in 1986 totaled $84 million. On an annual basis, the Massachusetts effort represents less than one percent of the the Federal expenditure, yet the Massachusetts program has produced a wealth of valuable information in a wide range of fields.

The findings summarized in this Section are divided into four catagories which correspond to the major research areas. These are, in order: **Aquatic Effects**, **Terrestrial Effects**, **Acid Deposition Monitoring**, and **Public Health and Cultural Effects**.

Virtually all of the results in this Section are taken from the research abstracts in Section IV or from the accompanying report, <u>Acid Rain in Massachusetts: The Massachusetts Acid Rain Research Program in Action</u>. The findings summarized here represent only a small percentage of the entire research effort, but perhaps the most important. These results stand on their own. However, in order to gain a more complete understanding of the scope of the problems created by acid deposition and the implications for the Commonwealth's natural and cultural environment, it is important that one read the attached abstracts and, if possible, the report of the National Acid Precipitation Assessment Program (NAPAP).

The points made in this summary section are not intended as a full discussion of the results of the research program. That more complete discussion is contained in 27 abstracts in Section IV. and the accompanying report, <u>Acid Rain in Massachusetts: The Massachusetts Acid Rain Research Program in Action</u>.

AQUATIC EFFECTS

> Sixty-four percent of Massachusetts' surface waters are vulnerable to acid deposition. Five and one-half percent (185 lakes, ponds and streams) are already acidified.

> Acidification of surface waters is influenced most by the acid neutralizing capacity (ANC) of the surrounding watershed as well as the rate of acid deposition. Thus, watersheds with soils incapable of buffering acidity are the most at risk. Watersheds in northern Worcester County and southeastern Massachusetts are the most sensitive, with the greatest percentage of acidified, critical and endangered surface waters.

> Even with constant or slightly declining levels of acid deposition, acidification of surface waters is likely to continue. The rate of acidification of lakes and streams is of crucial importance. Although few historical data exist, those that do indicate an alarming rate of loss of acid neutralizing capacity (ANC). A study of 34 drinking water reservoirs found that 18 of 34 showed significant declines of ANC since the 1940's. Applying these rates of loss of ANC to all Massachusetts surface waters suggests that, in 10 to 40 years, as many as an additional 800 lakes and streams in Massachusetts may become acidified.

> A decline in fish populations in Massachusetts is difficult to document because historical data are scarce, but what data there are suggest that surface water pH has declined and that fish survival has correspondingly declined. Of eighteen Millers River tributaries with healthy fish populations in the 1950's, two have lost all fish, eight have lost all but one species, and eight remain unchanged. In those that lost most or all fish, pH had dropped substantially; the unchanged tributaries had maintained historical pH levels.

> Studies have shown that acid deposition plays a role in the release of aluminum and other toxic metals into the environment. Bioaccumulation of toxic metals in fish suggests that organisms feeding on those fish will accumulate even higher levels of metals. Human health can be protected by restricting the intake of fish flesh, but the health of eagles, loons and other fish-eating birds and mammals cannot be so easily protected. Years of effort to restore the eagle, our national symbol, to Massachusetts' wilderness may be undermined by the insidious threat of heavy metals released by acid rain. Increased mobilization of metals in acidified watersheds and subsequent bioaccumulation of toxic metals in fish and wildlife may be one of the most serious consequences of acid rain and related air pollutants.

> Quabbin Reservoir sediments exhibit increasing concentrations of aluminum, a possible indication of increased dissolution of aluminum within the Quabbin watershed by acid deposition. A possible avoidance reaction by fish to elevated aluminum levels occured at Winsor Dam in 1985. No lake trout or other fish were found near the dam as indicated by sonar tracings made during the traditional lake trout spawning period of mid November, although this area has excellent spawning habitat and had been consistently utilized by spawning lake trout from 1965 to 1979.

> Recent studies found that mercury in fish flesh taken from several large fish at Quabbin exceeded levels acceptable for human consumption by as much as three and one-half times. In 1985, an immature bald eagle, which had been hacked at Quabbin in 1983 on a diet consisting mainly of Quabbin fish, was recovered in New York state, sick and unable to fly. The bird did not improve after several months and was eventually put to rest. Severe mercury poisoning was indicated by elevated blood levels. It is not known for certain where the eagle picked up the mercury, but the possibility exists that it may have been at Quabbin.

> Quabbin Reservoir has lost 75% of its acid neutralizing capacity in the past 40 years. Quabbin is Massachusetts' most important cold water fishery. In 1984 it was ranked as the second most frequently fished body of water in a statewide angler survey. Some 50,000 anglers annually harvest 25 - 30,000 kilograms of fish, primarily lake trout and smallmouth bass. In 1984 stocking of rainbow trout was discontinued when average annual return fell below 2% of stocked fish. Research showed that increased acidity and loss of alkalinity made it difficult for rainbow trout to survive. After seven years of increasing harvest, smallmouth bass show signs of decline beginning in 1985. Whereas it is too early to determine if increasing reservoir acidification is involved, concern exists that acidity may be playing a role. In 1984 the harvest of lake trout was one third less than predicted based on reservior volume. During the early 1980's, after six years of increasing lake trout harvest and releases, harvests began to decline sharply. Research to date has shown that loss of acid neutralizing capacity in the Quabbin can be correlated with decreases in lake trout reproduction and recruitment.

> It is not possible to predict when a zero alkalinity event in Quabbin may occur, as alkalinities are dependent on the rate of loss of watershed acid neutralizing capacity and the level of acid loading. However, using the trends in reservior alkalinity minima as a measure of watershed acid neutralizing capacity deterioration, there is an increased possibility of a zero alkalinity event after the early 1990's. Loss of sensitive aquatic species such as smelt, which are important links in the food chain, and the disruption of fish reproduction during low pH periods will harm the ecosystem as the reservoir progresses towards acidification.

> A 1984 survey of licensed anglers in Massachusetts demonstrated that each fishing trip in Massachusetts resulted in an average total expenditure of $11.95 and an average of $.95 in state tax revenue generated. Significant decreases in annual angler trips could have very serious effects on local economies and sizable impacts on state tax revenues.

> Although the loss of fish is a major concern, impacts on other plant and animal species are of equal significance to the overall health of aquatic ecosystems. Fresh water mussels, snails and crayfish require a supply of calcium and are often early casualties of acidification.

> Smelt were originally stocked at Quabbin to provide forage for game-fish. Their introduction was so successful that in the 1960's the population created a major headache for reservoir managers by plugging the intake screens for the water distribution system. Recent studies have shown, however, that the seven tributaries on the western side of Quabbin Reservior no longer support smelt spawning. Six of the seven tributaries on the eastern side support spawning but have occasional abnormal egg mortality, depending on the acidity of rainfall events during the spawning season. Of the original fourteen tributaries supporting smelt spawning in Quabbin Reservior, six have not seen spawning since 1980, two since 1982 and six still support spawning runs but experience periodically high egg mortality.

> The lethal effects of environmental acidification on fish are well established. Although acidification has been shown to result directly in mortality, it more commonly affects reproduction. Studies in Massachusetts have demonstrated that fish mortality in some acidic waters can be attributed to both environmental pH and metal concentrations, particularly aluminum.

TERRESTRIAL EFFECTS

> Interpretation of color infrared (CIR) photographs taken of all Massachusetts forests in 1984 and 1985 indicate that 24,287 acres showed obvious signs of stress and decline based on leaf discoloration, branch dieback, and dead trees. The stressed areas are concentrated in Bristol, Plymouth, Worcester and Berkshire counties.

> On-site examination of locations showing significant forest stress from the CIR photos indicates that insect and disease problems could account for most of the observed symptoms of decline. The only portion of the state to date that is exhibiting decline symptoms believed to be caused by air pollutants is approximately 2,500 acres of red spruce and sugar maple in the Mt. Greylock area. Many more acres, however, have not been adequately ground checked. Furthermore, the field activities in 1987 established that the decline and mortality first noticed in the 2500-acre section are wide spread throughout the Berkshire Hills of Western Mass.

> In Colrain, Massachusetts, studies of Norway spruce (a species showing severe decline symptoms in Europe) found most trees to be healthy or slightly damaged, but 4% were classified as moderately damaged or worse. Damage was characterized as loss of older foliage on the inner portions of the crown. These symptoms are similar to those occurring in mildly affected spruce stands in Germany for which there is some evidence that air pollution is a primary stress factor.

> Detailed information on red spruce mortality rates and decline symptoms was collected from six permanent study plots in Berkshire County. Mortality rates were high in all plots, with dead trees occurring in pockets rather than scattered uniformly throughout the stand. This pattern suggests the presence of a biotic, infectious agent capable of spreading through root or branch contact. Other symptoms observed within the stands, however, include flecking and mottling of foliage. These symptoms are commonly associated with air pollution injury in other species.

> A ground survey of some 440 sugar maple trees at 22 sites throughout western Massachusetts is cause for some considerable concern. Only 24% were rated in relatively good health, 60% in relatively poor health. The decline symptoms noted most often included dead branches scattered throughout the crown, chlorotic foliage, undersized leaves and premature fall coloration.

> These preliminary field results on Norway spruce, red spruce, and sugar maple clearly establish that forest decline is a significant problem for sensitive species in some areas of Massachusetts. Mortality rates are high in the red spruce forest and sugar maples display a variety of decline symptoms. Although acid rain has not been identified as a principal damage agent, there is some indication that it plays a significant role in both cases.

> Results from a separate study indicate that growth measurements and analysis for both red pine and white pine do not show any general, widespread pattern of decrease in growth which might be attributed to acid rain or air pollution in recent times. However, certain stands show abnormally high mortality and severe growth reductions, so site-related health and decline problems which may involve acid rain or air pollution cannot be ruled out.

> Some researchers have suggested that the decline and mortality in red spruce and sugar maple should be interpreted as an early warning sign of more serious effects to come. There is concern that if acid deposition continues at its current level the injury threshold for many more species may be exceeded. Should that occur, Massachusetts may well experience the widespread decline of tree species that has occurred in Europe.

> Massachusetts researchers continue to be concerned with two major hypotheses which have emerged to explain the phytoxicity of acid rain: 1) acid precipitation impacts on soils leading to nutrient leaching and mobilization of toxic metal ions which damage roots and affect nutrient and water uptake; 2) gaseous pollutants (primarily ozone) impact directly on above-ground plant parts, weakening plants to acid precipitation and other stresses.

> Studies at the Suburban Experiment Station in Waltham have shown that plants which are sensitive to pollutants like ozone produce pollen which is ozone-sensitive. Researchers have screened the pollen of many native and horticultural plant species for ozone sensitivity and found that ozone may well impact the reproductive ability of many important plant species.

> The long-term effects of ozone and acid rain on plant pollen may lead to changes in the composition of natural plant communities and differential survival of shade and forest trees. For example, it is believed that many of the most sensitive genotypes of ponderosa pine in southern California have been eliminateed. Such changes in forest ecosystems may affect the types and numbers of wildlife species they can support.

> Researchers in Massachusetts speculate that unless pollutant stresses are abated, we can expect to see the elimination of pollution sensitive plants in many parts the world. Continued study of plant diversity and related pollen sensitivity to pollutants will improve understanding of populations at risk.

> The effect of acid rain and air pollution has been evaluated for corn, apples and several flowers. The reproductive system in each case has shown sensitivity to these pollutants. There were measured differences among varieties of apple pollen tested, indicating that an acid precipitation event could reduce yields of some varieties more than others. The effects of simulated rain on pollen in apples and corn appears directly related to the acidity of a rain event.

> Tests with corn have indicated that acid rain affects both pollen and stigmatic tissue in the reproductive system. The number of seeds on an ear of corn is reduced when limited quantities of pollen are used in pollination of ears previously exposed to an acid rain event.

> These data concerning apples and corn indicate that crop and orchard yields could be reduced by pollution episodes during the time of pollination. The ultimate effect of pollution on yields appears to be related to the quantity of pollen available in the field. In normal cropping years with an abundance of available pollen, yields probably would not be reduced. However, in those years when dry weather, excessive temperatures or excessive rainfall reduce the quantities of pollen available, a pollution event at the time of pollination probably would affect the reproductive system enough to reduce plant yields.

ACID DEPOSITION MONITORING

> The average pH of precipitation in Massachusetts is 4.2. On every acre of the state, 0.3 - 0.7 pounds of hydrogen ion, 16.2 - 27.5 pounds of sulfate and 8 - 22 pounds of nitrate fall each year as a result of acid deposition.

> A variety of techniques continue to demonstrate that Massachusetts receives 70 - 90% of its acid deposition from sources outside the region.

> A single precipitation event was modeled using the MESOPUFF II model, and the results were compared with observations on wet sulfate deposition at two Massachusetts monitoring sites. For that event, the results showed that instate emission sources may have contributed as little as 2% of wet sulfate deposition at some sites and as much as 70% at other sites. Massachusetts efforts to model wet sulfate deposition have shown that there are large variations in deposition across the Commonwealth, resulting from emission sources within the state.

> Continued efforts to model deposition from in-state sources, combined with observations of total deposition at a site, will help Massachusetts researchers better understand the relative contribution of local emission sources to total deposition at any given site within the Commonwealth.

> Variability of acidic pollutant levels in the atmosphere is significant throughout the course of the year. For the two years of data collected at the Quabbin Summit monitoring site, sulfur dioxide and nitrogen oxides maintained higher concentrations in the winter than in the summer.

> Higher concentrations of sulfur dioxide and nitrogen dioxide are associated with winds from the southwest, as were reduced visibility and higher concentrations of particulates. These data continue to confirm that long range transport from sources of emissions located to the south and west of Massachusetts is a major source of pollution in Massachusetts and New England.

> Ozone concentrations were not associated with any particular local wind direction in the analysis of data gathered during the first year at the Quabbin Summit monitoring site. This may be a consequence of the regional nature of ozone pollution and the fact that air stagnation can create elevated levels of ozone.

> Regional haze resulting from sulfate particulates in the air has caused a 50% decline in visibility in rural New England since the 1950's. It has been estimated that reducing this regional haze by as little as 13% could result in as much as 126 million additional dollars generated through tourism.

> Ozone concentrations of 0.05 ppm, which are sufficient to cause injury to ozone sensitive plant species, were frequently met and exceeded during ozone monitoring in 1986 and 1987 on Mt. Greylock. Ozone sensitive tobacco plants placed as biological monitors showed typical severe ozone injury symptoms each week from June through September during 1986.

PUBLIC HEALTH AND CULTURAL EFFECTS

HEALTH

> Acidic (aggressive) drinking water can corrode distribution pipes, resulting in toxic metal levels in excess of drinking water standards. A survey of Massachusetts municipal drinking waters found that 73% were highly aggressive and 25% were moderately aggressive.

> A national survey of rural (non-public) water supplies showed that drinking water standards for lead were exceeded in 9.6% of households in the Northeast, 1.6% for cadmium, 2% for selenium, 16% for iron, 16.9% for manganese and 22% for mercury. These data, combined with growing evidence that acidic deposition can result in the mobilization of toxic metals in the environment, give cause for concern that the public health is at a somewhat increased level of risk.

> Increased sulfate from acid deposition may facilitate increases in the conversion of mercury into its most toxic form, through the action of sulfur reducing bacteria in aquatic systems. Once in this form, mercury can enter drinking water supplies or the food chain, where it may bioaccumulate.

> Atmospheric pollution has been related to hospitalization in Massachusetts for respiratory disease. Massachusetts researchers have developed an interim, revised pollution standards index for Massachusetts, based solely on Massachusetts data, which includes new pollution standards for sulfur dioxide, nitrogen dioxide, carbon monoxide and fine particulate matter.

> Water provided to the metropolitan Boston distribution system must be treated to reduce acidity and minimize dissolution of lead from distribution pipes. Treatment costs are currently $1.3 million per year.

CULTURAL

> Acid deposition can cause etching and erosion of culturally important monuments and buildings. Massachusetts is richer than most states in such artistic and historic objects, with more than 340 bronze statues and 80,000 historic properties. Bronze and marble statues, tombstones and marble building facades are being destroyed throughout the state. Masonry mortar, brick and limestone construction materials are vulnerable to damage from atmospheric acid.

> Annual replacement costs for bare galvanized steel destroyed by acid deposition or sulfur dioxide in Boston is estimated at over $33 million per year; damage to paint is estimated at $31 million per year.

> Costly protective coatings for metals must be regularly maintained to prevent further disfigurement. Protective materials do not exist for stone materials. Once stone materials start to deteriorate from acid etching, repeated freezing and thawing accelerate the process.

> There are some 340 outdoor bronze statues of historical significance registered with the Massachusetts Historical Commission. The cost of cleaning and coating a small statue is $2000 and lasts for only three to five years. The statues must be waxed each year at an additional cost of $250. To protect only the most important bronze statues in Massachusetts would cost between two to six million dollars over a ten year period

> The Massachusetts Historical Commission has paper files on over 100,000 cultural and historic resources within the Commonwealth. A rapid protocol for identifying resources at risk to acid deposition and air pollutants is now being developed. Future research efforts will be directed toward identifying priority cultural resources across the state, determining how the condition of these resources varies according to location, and evaluating what mitigative measures may be available to control damage to these resources.

III. RECOMMENDATIONS FOR FUTURE ACTION

The Massachusetts Acid Rain Research Program clearly has produced a wealth of important benefits and insights. While research done in Massachusetts and elsewhere continues to document serious environmental deterioration in the face of this problem, this same research has shown that the problem is more complex than was first thought. There exists, therefore, a strong need to increase our efforts towards understanding and resolving the problem at all levels. It is clear that acid rain is a serious problem; we must address it by reducing pollutant emissions as well as by conducting further research. The major means by which the Commonwealth can accomplish these tasks are:

> Proceeding with emission controls within the Commonwealth, focusing initially on existing SO_2. control legislation, but eventually considering controls for NO_x and related oxidants.

> Continuing acid rain research within the Commonwealth, based on the needs identified by research conducted previously, and continuing efforts at public education.

> Continuing efforts to achieve responsible action at the national level.

To date, elected and appointed officials within the Commonwealth have employed a multi-faceted approach which has included a variety of measures designed to limit acid rain damage within the Commonwealth, as well as regional or national measures designed to assist other states or the federal government in reducing acid rain. This report recommends that a broad-based, multi-level approach be continued as the most effective means of achieving reductions in the impacts of acid rain upon Massachusetts.

A. <u>In-State Emissions Control Legislation</u>

1. Implementation of existing legislation limiting SO_2 emissions within the Commonwealth

In 1985 the Massachusetts legislature passed legislation (Chapter 590) limiting SO_2 emissions from sources within the Commonwealth. This law includes two main components; the first is a "cap" on statewide SO_2 emissions based on the annual average SO_2 emissions for the period 1979 to 1982. The DEQE must ensure that levels of SO_2 emitted from all anthropogenic sources combined do not exceed the cap. The DEQE has been implementing this program since 1986. To date, annual SO_2 emissions have remained safely below the cap.

The second component of the legislation calls for the DEQE to establish regulations limiting SO_2 emissions from all major sources to 1.2 pounds of SO_2 per million BTU's (1.2 lbs. SO_2/MBTU) of fuel input, provided that no national or comprehensive regional acid rain legislation was enacted by the end of 1987. As no such national or regional legislation was adopted, the DEQE is now proceeding with the development of these regulations, which will result in major Massachusetts facilities meeting an average rate of 1.2 lbs. SO_2/MBTU by January 1, 1995.

2. Consideration of legislation limiting NO_x emissions within the Commonwealth, pending analysis of the results of an in-depth NO_x investigation

Oxides of nitrogen are thought to account for 30% to 40% of atmospheric acid in Massachusetts. It is estimated that 40% to 50% of the NO_x emissions in the Commonwealth are from mobile sources (automobiles, trucks, buses). The DEQE's Division of Air Quality Control has the authority to regulate NO_x emissions, but feels that more needs to be known about NO_x, particularly regarding the relative contributions of various sources to NO_x levels and the relationship of NO_x to ozone and other air pollutants. Current DEQE data indicate that NO_x levels appear to be increasing, and DEQE predictions show a 4% increase in NO_x by 1992 (DEQE, 1987). DEQE is currently undertaking a modest research program on NO_x. Based on the results of the DEQE's NO_x investigations, the legislature should then consider legislation to control or limit NO_x emissions within the Commonwealth.

3. Legislation requiring that the least polluting alternative be considered in public issues such as setting of electricity rates and transportation planning

Ultimately the economic well-being of the Commonwealth depends upon both its environmental quality and an adequate supply of energy. Because air pollutants, including those contributing to acid rain, are closely related to other issues such as electricity generation and transportation, decisions regarding such issues should include consideration of the effects such decisions are likely to have on acid rain and other forms of air pollution within the Commonwealth. It is recommended that the legislature require that agencies and commissions responsible for such decisions consider the least polluting alternative as an integral part of the decision making process. Mandatory consideration of the air pollution consequences of various options, in addition to cost, could help maintain the Commonwealth's environmental quality while sustaining economic growth. Increased interagency coordination, particularly between state environmental and energy agencies, could facilitate this. Given the potential conflicts that can develop between the policies and concerns of energy and environmental agencies, it may be important to provide a formal means of authoritatively resolving interagency issues within state government.

B. Research and Public Education Within Massachusetts

The Massachusetts Acid Rain Monitoring Project (ARM), the Massachusetts Acid Rain Research Program, the Call to Action issued by DEQE in 1984, and related state research efforts have been highly effective in informing public officials and educating the public about the threat of acid rain to the Commonwealth's natural and cultural resources. The information produced by this research has provided substantial evidence to support the contention that acid rain is a serious threat in Massachusetts, and has enhanced the Commonwealth's efforts to call for reductions in acid rain at the national level. Specific efforts at public education, such as the booklet Acid Rain in Massachusetts: The Massachusetts Acid Rain Research Program in Action, being produced concurrently with this report, can be an effective means of disseminating research results to the public. In addition, the Commonwealth's funding of acid rain research have proven to be effective in attracting federal funds

for related projects. State funding for research tends to have a multiplier effect in this way.

Many questions remain to be answered, however, and a variety of suggestions for needed research have been made by members of the Acid Rain Working Group, the Scientific Advisory Council, state agency personnel, and other interested parties. These suggestions include:

Atmospheric:
- research into the relationships of acid rain pollutants to other air pollutants, particularly ozone
- expanded air quality monitoring within the Commonwealth, particularly at sites remote from anthropogenic sources
- investigation of the impact of small power plants and cogenerators on acid rain and related regulations
- demonstration projects for acid rain control technologies
- possible use of meso scale modeling in determining contributions of in-state vs. out-of-state acid rain sources and in developing and evaluating Massachusetts regulations

Aquatic:
- investigation of the impacts of acid rain on drinking water quality, particularly as it comes out of household taps
- continuance of the ARM Project, Phase III, long term monitoring of selected lakes and streams
- investigation of the relationships between acidification and heavy metals, including mobilization of metals from watersheds, metal concentrations in sediments and surface waters, and concentrations of metals in fish
- continued research into aquatic mitigation measures

Terrestrial:
- increased research into the area of forest-atmosphere interrelationships, such as the possible synergistic effect of ozone and acid rain as forest stressors, the ecological importance of red spruce as a possible biological warning sign, and extension of the work done with acid rain effects on pollen to forest species
- improved air quality and acid deposition monitoring at the permanent forest study field sites maintained by the DEM
- establishment of a long term biomonitoring program to uniformly measure key forest health parameters

Cultural:
- continued inventorying of cultural and historical resources at risk from acidic deposition
- evaluation of mitigation measures for cultural resources

Public Education:
- increased efforts toward disseminating research results and educating the public about acid rain, including the new Pollution Standard Index being developed by the DEQE
- continued participation in Acid Rain Awareness Week at both the state and regional/international levels

Specific measures relevant to the research objectives identified above are given below.

1. Continued funding of the Acid Rain Research Program

The Scientific Advisory Council has been responsible for establishing research priorities, such as those listed above, for the state Acid Rain Research Program. Council members expressed concern that this program continue as an integrated, interagency program, and not be dissolved within the various departments and divisions. It is recommended that this program continue as a distinct program coordinated through the Executive Office of Environmental Affairs. Given that, once enacted, any federal acid rain legislation is likely to involve a ten year period before emission reductions become effective, it is recommended that a long term source of funding for the Acid Rain Research Program be established.

. This program has proven to be an effective means of accomplishing a wide range of different research objectives through the use of researchers drawn from colleges, universities, state agencies and private firms throughout the state. Such personnel and technical resources for research are abundant in Massachusetts. The information produced by this research provides evidence relevant to current policy issues as well as help define cost effective implementation measures for control strategies.

The Acid Rain Monitoring Project, which is currently funded as a separate line item, should continue as such. The ARM Project has been expanded into the Cooperative Aquatic Research Program (CARP), which is administered through the Division of Fisheries and Wildlife. This program has been a highly cost effective means of accomplishing research in the area of acid rain effects on aquatic systems.

It is recommended that the DEQE's administration of projects be streamlined to facilitate the timely and effective completion of research funded through that agency. Projects funded through that agency have suffered excessive delays and procedural difficulties which have interfered with the progress of research.

2. Funding to establish an air pollution research program within an appropriate state agency for the purpose of investigating linkages among various air pollutants and developing means of comprehensive control of air pollution

A number of people suggested increased funding for additional state agency personnel to enforce existing regulations, implement the Chapter 590 SO_2 control regulations, and develop more complex strategies of controlling acid rain and other air pollutants by developing a comprehensive air pollution control scenario. In addition, it is felt that a basis for developing air pollution control technology demonstration projects is needed within the state.

The new EOEA Office of Research, Testing and Standards should consider establishing an Air Pollution Research and Demonstration Program within the DEQE. Such a program, which would include new funded state

employee positions, would provide an on-going means of addressing air pollution questions in a comprehensive, well integrated way. This program would complement the existing Acid Rain Research Program, which uses contract

researchers and focuses exclusively on the acid rain issue. The program would take an overview of air pollution research and demonstration needs, and evaluate the results of research from a variety of sources, including the Acid Rain Research Program. By aiding the development and demonstration of more complex pollution control strategies, the initial taxpayer expense of the program could be returned as consumer savings, as more complex control strategies can allow utilities and industry to pursue more cost effective control methods, with potential savings to the consumer. Control technology demonstration projects could have similar public benefits, by encouraging industry and utilities to implement cost effective pollution reduction measures. A bill which proposes to fund the Air Pollution Research and Demonstration Program through automobile inspection fees is now before the state legislature.

3. Funding for continued investigation of nitrogen (di)oxide (NO_x) emissions and an assessment of their role in acid rain impacts within the Commonwealth

The DEQE Division of Air Quality Control has recently sent out a request for proposals to conduct a "Nitrogen Dioxide Assessment Study for Metropolitan Boston and Pioneer Valley Air Pollution Control Districts: Current Analysis and Future Trends". This work should be continued and expanded to permit the DEQE to adequately assess the role of NO_x in the Commonwealth's air pollution scenario, and evaluate what control measures, if any, should be proposed.

C. National and Regional Measures

Since 1980, Massachusetts officials have been involved in efforts to publicly identify the regional risks associated with acid rain and to develop an effective acid rain control program at the national level. These efforts have included participation by the governor in resolutions and other actions undertaken by the New England Governors' Conference and the Conference of the New England Governors and the Eastern Canadian Premiers, participation of state agency personnel in regional task forces and commissions, participation of the Commonwealth in lawsuits filed against the U.S.E.P.A. and others, the establishment of an annual Acid Rain Awareness Week, and sponsorship of federal acid rain control legislation by the Massachusetts Congressional delegation.

The New England Governors, alone and together with the Eastern Canadian Premiers, have adopted a series of resolutions since 1982 which call for significant national emissions reductions for SO_2 and NO_x, have evaluated economic impacts and proposed funding mechanisms for control programs, promoted regional cooperation and communication, and advocated a transboundary international accord between the United States and Canada.

State agency personnel have participated in the Northeast Regional Task Force on Atmospheric Deposition, the New England Governors' Conference Acid Rain Task Force and several regional and international work groups.

These organizations have had a focus on regional cooperation, and have produced reports assessing regional acid rain damage and calculating required emission reductions.

Since 1981, Massachusetts has participated in several lawsuits filed by northeastern states in attempts to force the federal government to require significant national emissions reductions.

Acid Rain Awareness Week has provided an effective vehicle for public education about the acid rain problem, and has provided a forum for discussion of the issue and publicity for proposed acid rain control legislation.

Several significant national acid rain control bills have been sponsored by members of the Massachusetts Congressional delegation in the past several years.

It is recommended that this multi-faceted approach continue, and that efforts in this area be increased, until effective legislation is enacted to reduce emissions of acid precursors (SO_2 and NO_x) on a national scale.

1. Continued efforts to promote national acid rain legislation

It is generally agreed that any widely effective acid rain control strategy must involve national legislation and be applied over a large scale regional or national basis. This is true because of the wide distribution of emission sources of acid rain precursors, and the broad geographic regions over which acidic pollutants are transported and deposited once emitted into the atmosphere. For example, at least 70% to 90% of the acid deposited in Massachusetts is thought to originate outside the Commonwealth. For this reason, it is important that Massachusetts officials continue to press for national acid rain control legislation in a number of different fora. The United States congressional delegation from Massachusetts has been active in sponsoring substantive acid rain control legislation, and Governor Dukakis has actively pursued this topic at regional and national governors' meetings.

The essential components of national acid rain legislation which are supported by state officials and the New England Governors' Conference are as follows:

- 48 state coverage

- annual reductions in SO_2 of at least 10 million tons and reductions in NO_x of at least 4 million tons, in two phases

- flexibility for states in implementing required reductions

- a funding mechanism which addresses the financial impacts of program implementation

It is also recommended that the Commonwealth support, however possible, federally funded research and development of clean coal technology. By providing a means of efficiently converting coal to energy, this technology could help keep coal miners employed, while simultaneously reducing SO_2 and

NO_x emissions. The Commonwealth should aggressively assist industry in obtaining federal funding for development and demonstration of this technology.

2. Increased efforts to integrate Massachusetts research with regional and national research programs

Various means of integrating Massachusetts research with regional and national efforts have been suggested. The National Acid Precipitation Assessment Program (NAPAP) has been criticized strongly in Massachusetts and other states. Increased state agency input and review in the NAPAP process is strongly recommended. The benefits of the Massachusetts research and regulatory programs should be shared with the national congress and federal agencies. The Massachusetts comprehensive air quality/acid deposition monitoring sites has providfed much needed information for the national program, but additional staff is needed to set up mechanisms for integrating the state and federal research. It is recommended that this monitoring program be expanded and staffed with additional personnel. It also is recommended that a staff position be funded to coordinate state research activities with those of federal agencies.

IV. ACID DEPOSITION RESEARCH PROGRAM ABSTRACTS

This section contains the abstracts of the 27 research projects comprising the Massachusetts Acid Rain Research Program.

THE TWENTY-SEVEN (27) RESEARCH ABSTRACTS

AQUATIC EFFECTS

WATER QUALITY MONITORING

The Acid Rain Monitoring Project (ARM) Phase III - DFWELE

Effects of Atmospheric Wet Deposition on the Water Quality of Two Streams - MDC

Hydrologic Controls on the Chemical Response of Streams to Precipitation Events in Central Massachusetts: IMplication for Aluminum Mobility - DFWELE

Stimulation of Mercury Methylation by Acid Deposition - DFWELE

Role of Sulfate Reduction in Mitigating the Effects if Acid Deposition in Lakes - DFWELE

BIOLOGICAL EFFECTS

Acidification and Fish Harvest Trends at Quabbin Reservoir - DFWELE

Physiological Stress Indicators in Fishes and their Potential for Application in Field Studies - DFWELE

Reproductive Failure due to Environmental pH and Ionic Factors in Landlocked Rainbow Smelt (Osmerus mordax) - DFWELE

Effects of Acid Precipitation and Breeding Strategies on Salamandar Communities in Massachusetts - DFWELE

MITIGATION

Mitigative Lake Liming - DFWELE

Physical, Chemical and Biological Impacts of Liming on a Cape Cod Kettle Pond - DFWELE

Ecological and Chemical Responses of Whetstone Brook during Continuous Treatment with Calcium Carbonate - DFWELE

A Preliminary Economic Assessment of Liming Acidified Lakes and Ponds in Massachusetts - DFWELE

Investigation of Forest Management Impacts on Watershed Hydrology and Aquatic Chemistry - MDC

Biological Monitoring Program, Dickey Brook Watershed, Quabbin Reservoir, 1985-1986 - MDC

TERRESTRIAL EFFECTS

FORESTS

Forest Stress Analysis - DEM

Growth of Massachusetts Forests in Relation to Potential Effects from Acid Deposition - DEM

AGRICULTURE

Predicting Species Tolerance in Nursery Crops to Acid Precipitation/Gaseous Air Pollutant Complex using Pollen Screen - DFA

The Acid Rain-Ozone Pollution Complex and Reproductive Processing in Crop Plants - DFA

Acid Precipitation and Physiological Action of Crop Growth Regulators, Herbicides and Crop Protectants - DFA

ACID DEPOSITION MONITORING

Quabbin Summit Air Quality Monitoring Project - DEQE

Ozone Monitoring at Mt. Greylock - DEQE

Wet Deposition Chemistry and Air Quality Data Analysis Project - DEQE

Acid Deposition Mesoscale Modeling Study - DEQE

PUBLIC HEALTH AND CULTURAL EFFECTS

Massachusetts Pollution Standard Index (PSI) for Air Pollutants - DEQE

Design of a Drinking Water Quality Monitoring Program - DEQE

Effects of Acidic Deposition on Cultural and Historic Resources in Massachusetts - DEQE

AQUATIC EFFECTS

WATER QUALITY MONITORING

5 ABSTRACTS

AQUATIC EFFECTS

WATER QUALITY MONITORING

The Acid Rain Monitoring Project (ARM) Phase III - DFWELE

Effects of Atmospheric Wet Deposition on the Water Quality of Two Streams - MDC

Hydrologic Controls on the Chemical Response of Streams to Precipitation Events in Central Massachusetts: Implication for Aluminum Mobility - DFWELE

Stimulation of Mercury Methylation by Acid Deposition - DFWELE

Role of Sulfate Reduction in Mitigating the Effects if Acid Deposition in Lakes - DFWELE

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	The Acid Rain Monitoring Project (ARM) Phase III Cooperative Aquatic Research Program (CARP)
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter H. Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATORS	Paul Jos. Godfrey, Marie-Francoise Walk and O. T. Zajicek Water Resources Research Center and Department of Chemistry University of Massachusetts, Amherst, MA 01003

OBJECTIVES

Introduction

Acid rain is recognized as an insidious threat to environments in many parts of the world. Impacts of acid precipitation on water resources in Scandinavia, eastern Canada, the Adirondacks, eastern United States and the Rocky Mountains have been documented in the scientific literature. One dramatic indication of these impacts has been the loss of fish in thousands of lakes: Sweden - 5,000, Norway - 1,500, Adirondacks - 200-400, Canada - more than 400.

While the impacts of acid precipitation in these areas received early attention, the impact of acid rain on Massachusetts was little studied prior to 1983. A comprehensive data base describing the chemistry of surface waters in the state did not exist. At that time, estimates from limited data indicated that 60% of Massachusetts' reservoirs and 40% of the state's 2,675 ponds and lakes were endangered. No estimates were available for streams.

The general public was largely unaware of the potential danger to the Massachusetts environment posed by acid deposition. Those with some knowledge of acid deposition believed that the Adirondacks, northern New England and Canada but not Massachusetts were impacted.

Objectives

A need clearly existed for scientific, comprehensive documentation of the impacts and potential impacts of acid deposition on the water resources in Massachusetts. The Acid Rain Monitoring Project (ARM) was begun in the fall of 1982 to:

1) Evaluate the current status of a large number of Massachusetts' lakes and streams using high standards of sample collection and analysis.

2) Develop a large but well coordinated group of volunteers to collect and analyze samples -- volunteers who would become more intimately familiar with local and statewide acid rain impacts and who would form a potential nucleus for strong citizen action to encourage solutions to the problem.

3) Produce a computerized data base which can be referenced by Massachusetts water resources researchers and can provide a basis from which to identify areas requiring further research.

4) Conduct a review of all historical data relating to water bodies covered, including all data available from the Divisions of Water Pollution Control and Fisheries and Wildlife.

5) Analyze the data according to both political and natural watershed boundaries and evaluate the results in relation to geological and other natural characteristics, including rainfall data.

6) Increase the level of public awareness through publication of technical reports, monthly newsletter, media releases and communication between the volunteers and their communities.

METHODS

Five hundred lake and stream sampling sites were selected using a stratified random design based on use of six sensitivity categories. An additional 300 special interest sites were added to meet the needs of the Division of Fisheries & Wildlife, other state agencies, U.S. EPA and ARM participant organizations.

Samples are collected quarterly (January, April, July and October) by approximately 300 volunteers following a standard sampling protocol. Within 24 hours, usually within 12 hours, pH and alkalinity are analyzed by 20 participating volunteer laboratories using consistent analytical protocols. Two aliquots of each sample are separated; one is refrigerated and the other is preserved with nitric acid. Both aliquots are returned to UMASS for analysis of 18 cations and 4 anions.

Quality control for analyses conducted at volunteer laboratories uses blind and double blind samples provided by the UMASS lab. Reagents and equipment are standardized as much as possible. The UMASS lab participates in several QA/QC audit programs run by the U.S. EPA, U.S. Fish & Wildlife Service, and International Science & Technology, Inc. The lab is certified for these analyses by the Department of Environmental Quality Engineering Lawrence Experiment Station.

The resulting database of water chemistry for surface waters in Massachusetts is maintained on IBM-compatible microcomputer using dBase III+. Statistical analyses are performed using SAS. Many utility programs have been written to permit easy access to these data. Results are returned to volunteers

in very timely fashion. Summaries of results are prepared as needed for general public release. All requests by agencies and individuals are filled as soon as possible.

A brief review of the findings of ARM I and II follows as context for the long-term effort. ARM I determined for approximately 40% of the surface waters in Massachusetts that 57% had an average annual alkalinity of less than 10 mg/l (200 feq/l) and 19% had alkalinities less than 2 mg/l (40 feq/l). Geographic and seasonal variations in water chemistry were significant. Quarterly analysis of samples for major anions and cations, aluminum and color indicated that the likely source of high surface water acidity and sulfate concentrations is atmospheric deposition of strong mineral acids.

In ARM II, approximately 2500 surface waters were sampled twice annually. Average values for all water bodies fit the seasonal curve from ARM I reasonably well, particularly for alkalinity. The seasonal pattern from ARM I might then be used to correct historical data for differences in sampling date. ARM I and II sampled different water bodies, but the percentages for each sensitivity category differ little between the two surveys. More than 1500 lakes and ponds and 900 streams were sampled. Lakes exhibit greater sensitivity overall, but the difference is smaller in spring than in fall.

The October sampling coincided closely with U.S. EPA Eastern Lakes Survey (ELS). 80 of the 99 lakes included in the ELS were surveyed by ARM. The correlation between ELS and ARM pH values was 0.83; for alkalinity, the correlation was 0.98. A comparison between the number of Massachusetts lakes in three sensitivity categories based on projections by the U.S. EPA from the ELS versus the actual counts from the ARM Project reveal serious underestimation by the EPA projections.

Evaluation of the data on cations and anions is underway.

RESULTS

Although all work on ARM II is not completed, preliminary results from ARM III are available for pH and alkalinity. The data spanning three years for 401 lakes and streams show that 214 surface waters improved slightly, 9 stayed the same and 88 deteriorated. The improvement in the majority of surface waters was not totally unanticipated because wet acid loading had declined by more than 50% during the period of investigation. 38% of those deteriorating are found in the extremely sensitive north-central region of Massachusetts. Of the 121 surface waters in critical condition ($0 < \text{alkalinity} \leq 2$ mg/l), 54% had worsened, 35% improved and 11% remained the same.

STATUS

This project was started in September 1983 and will be completed in September 1995.

ANALYSIS AND INTERPRETATION

In the first year (Phase I) of the ARM Project nearly all of these objectives were achieved. A volunteer network of 1000 individuals sampled 2000 surface waters, most on a monthly basis. A similar network of 73 volunteer laboratories provided high quality preliminary analysis. ARM provided a complete picture of the seasonal variation in more than 1000 surface waters. Phase II focused on completing the survey of all surface waters in the state (approximately 2500 more) and providing a more extensive analysis of water chemistry. Based on the seasonal picture developed in ARM I, two representative sampling dates were chosen -- the first in October to coincide with the timing of the U.S. EPA Eastern Lakes Survey, and the second in April at the most critically acidic time of the year.

Together, the Phase I and II databases represent a comprehensive, up-to-date compilation of data regarding the sensitivity of Massachusetts' water resources to acidification. These data provide us with a contemporary baseline against which to compare both historical and future measurements of surface water quality but do not, of themselves, permit an evaluation of present trends. The purpose of the Phase III of the ARM Project is to conduct a ten-year, long-term monitoring program of selected lakes and streams designed to assess the current rate of acidification of Massachusetts' surface waters and identify other on-going trends in water chemistry.

<u>Publications and Presentations</u>

The Massachusetts Acid Rain Monitoring Project (A.R.M.): Phase I. P.J. Godfrey, A. Ruby III, O.T. Zajicek. 1985. Publication No. 147. Water Resources Research Center, University of Massachusetts, Amherst, MA.

The Massachusetts Acid Rain Monitoring Project (A.R.M.): Phase II. P.J. Godfrey, A. Ruby III, O.T. Zajicek. 1988. Publication No. 159. Water Resources Research Center, University of Massachusetts, Amherst, MA.

The Acid Rain Monitoring Project, Phase II. P.J. Godfrey, A. Ruby III, O.T. Zajicek. Presentation at the Northeast Fisheries Conference, Boston, MA. May 4, 1987.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Effects of Atmospheric Wet Deposition on the Water Quality of Two Streams
AGENCY	Metropolitan District Commission
PROJECT MANAGERS	Alfred Ferullo, (former) MDC Joseph McGinn and Karen Eager, MDC Arthur Screpetis, DEQE/DWPC
PRINCIPAL INVESTIGATORS	Rochelle Rittmaster, (former) USGS Jeffrey Strause, Michael Frimpter, USGS

OBJECTIVES

The primary objective is to describe the effects of acid precipitation on stream water quality in the West Branch Swift River and East Branch Fever Brook watersheds, which discharge to Quabbin Reservoir. This is to be accomplished through interpretation of hydrologic and water quality data collected over a 19-month period from December, 1983 through August, 1985.

METHODS

Gaging and Sampling

Daily precipitation data from the National Oceanographic and Atmospheric Administration (NOAA) gaging station in New Salem, Massachusetts were used in this study. Precipitation samples for chemical analysis were collected each week from a wet-dry deposition collector located about 2.5 miles from the NOAA station.

Stream stage was recorded continuously from November 1983 through September of 1985 at one site near the mouth of each watershed. Stage-discharge relationships were established during the first year of the project, with discharge determined on a weekly basis, and additionally during peak flow event. These rating curves were augmented with additional flow measurements periodically during the remainder of the study.

Stream water samples for chemical analysis were collected each week from the gaging station sites. A number of sampling runs which included upstream tributary sites in addition to the gaging station sites were conducted. These were scheduled to cover the full range of seasonal and hydrologic conditions.

Chemical Analysis

Precipitation chemistry was characterized according to the parameters listed in Table 1. Exceptions occurred when the quantity collected was insuf-

ficient for complete analysis or on rare occasions when the sample was contaminated in the deposition collector with leaves or other materials.

Surface water samples were analyzed for the constituents listed in Table 2, in addition to those listed in Table 1.

Samples were filtered, preserved, and chilled in the field. Temperature, pH, and conductivity were measured at the time of collection, using equipment designed and calibrated for low ionic strength waters.

TABLE 1 - Precipitation Analysis

specific conductance	nitrate-N	iron
pH	chloride	lead *
calcium	fluoride	managanese *
magnesium	sulfate	mercury *
sodium	orthophosphorus	selenium
potassium	organic carbon	vanadium
ammonia-N *	copper	

TABLE 2 - Additional Analyses: Stream Samples

temperature	dissolved solids	arsenic *
alkalinity	silica	copper *
hardness	aluminum *	iron *

* For stream samples, occaisional determination of total quantities (unfiltered samples) were made in addition to analyses of filtered samples. All other analyses were for the dissolved fractions passing a 0.4 or 0.1 micron filter.

<u>Data Analysis and Reduction</u>

Continuous hydrographs for the two river gaging stations were reduced to daily mean discharge values. The hydrographs were also analyzed graphically to estimate the baseflow component and to observe its variation over time.

Mass loads of chemical constituents from wet deposition were calculated from precipitation records and precipitation chemistry results.

Mass export loads for some stream water constituents were determined using estimated daily concentrations and the mean discharge for that day. This was necessary for those constituent concentrations which were flow dependent, because flow varied substantially over many of the weekly sampling periods. To estimate the daily concentrations and mass loads for these components, measured concentrations were regressed against instantaneous discharge values for the time of sampling. Of the number of regression models that were tried, the one giving the best correlation was used to estimate the concentration and

mass load. Transport of solutes that did not exhibit strong flow dependencies was calculated using the results from the weekly samples. Net transport or retention of a constituent was taken as the difference between cumulative precipitation loads and stream transport loads for the period of study.

RESULTS

Precipitation

Precipitation volumes recorded during the study period varied from substantially above average during the winter and spring of 1984 to mild drought conditions over the remainder of the period. Hydrogen constituted 75% of precipitation cation equivalence, and 97% of this acid load derived from sources other than normal atmospheric CO_2.

Weighted average wet deposition chemistry differed noticeably from water year 1984 to water year 1985. The lower hydrogen, sulfate and nitrate concentrations, and higher magnesium, sodium and chloride concentrations observed during water year 1984 were attributed to differences in precipitation patterns for that year. The coastal storms dominating the winter and spring were thought to cause increased loads of ocean derived salts and diluted levels of atmospheric acids. Over the period of study, precipitation pH ranged from 3.6 to 5.0 with a volume weighted average of 4.2.

Hydrology

Average annual discharge per unit area was 6850 cubic meters per hectare (1.98 cfs per square mile) in the Swift River watershed, and 6550 cubic meters per hectare (1.89 cfs per square mile) in the Fever Brook basin. These values are comparable to the average annual yield of 6700 cubic meters per hectare reported for Cadwell Creek.

The estimated baseflow component of total discharge from the East Branch Swift River was 49 percent. Swift River baseflow contributed 64% of the total weathering base cation flux, and only 17% of the net hydrogen load. For Fever Brook, estimated baseflow was 38% of discharge, but still yielded 64% of net base cation export and 21% of hydrogen output.

For the period of record, Swift River streamflow totaled 44.2% of incident precipitation and Fever Brook yielded 42.2 percent.

Stream Water Quality

Weighted average concentrations and mass transport values for major anions and cations were similar in both river basins, with the notable exception of sodium and chloride. The cumulative export load per unit area for both of these ions was much higher for the Fever Brook basin, although it constituted a significant portion of total Swift River ion export as well. The high levels of sodium and chloride in streamflow were largely attributed to road salt applications. Other less pronounced differences in average concentrations and export loads per unit area were observed, including higher output of sulfate, silica and calcium, and lower export loads of magnesium, potassium and alkalinity for the West Branch Swift River than for East Branch Fever Brook.

Hydrogen ion levels in Swift River Samples were directly proportional to discharge, and pH ranged from highs of 6.9 for extreme low flow episodes to lows of 5.1 during storm and snowmelt events, with a flow weighted average of 5.75. Similarly, alkalinity was inversely proportional to discharge; ranging from 0.2 mg/l to 6.1 mg/l (as $CaC0_3$) with an average of 1.1 mg/l.

At the main Fever Brook sampling station, hydrogen ion levels were less consistently correlated with discharge, indicating that factors other than deposition loads influenced pH. Here, the pH range was more narrow, with minimum values of 5.5-5.7 accompanying both maximum annual and minimum mid-summer flows. The highest values of pH 6.0 to 6.3 typically occurred during periods of intermediate discharge in the fall, winter, and spring. The midsummer decreases of 0.2-0.6 pH units appeared to be associated with elevated organic carbon, slowly increasing alkalinity and decreased sulfate levels. The flow weighted average pH for the study period was 5.64.

Other differences in seasonal and discharge related water quality parameters were apparent. Organic carbon ranged from 1.5 to 10 mg/l in the Swift River, and from 3.0 to 12 mg/l in Fever Brook. For the former, annual peak concentrations coincided with runoff and snowmelt events, and decreased to a minimum under low flow conditions. For the latter, maximum organic carbon levels coincided with low flow, although less marked increases following rainfall and snowmelt were observed as well.

Sulfate levels in the Swift River generally ranged between 6 and 8 mg/l and did not exhibit significant correlation with discharge. In Fever Brook sulfate ranged between 2.7 and 8.7 mg/l, reaching sustained high values during periods of intermediate discharge in the fall, winter and spring. During such periods, increases in flow produced proportional decreases in sulfate levels. Sulfate levels here declined seasonally beginning in mid-summer and reaching annual minima of approximately 3 mg/l in late summer/early fall low flow episodes.

The results of synoptic sampling runs conducted under a range of seasonal and hydrologic conditions also illustrate the effects of differences between the two watersheds.

For the Swift River runs, pH was consistently lowest and aluminum consistently highest at headwater stations. This pattern was apparent over the range of discharge levels, however peak aluminum levels were observed under peak flow conditions. Levels of calcium, magnesium and potassium did not show appreciable spatial patterns. Silica results showed small increases with distance downstream except under baseflow conditions. Sulfate, sodium, and chloride were also highest downstream except under extremely high flow conditions, in which case no spatial pattern was evident.

Water quality at one tributary site in the Swift River basin differed significantly from that typical of all the others. Water from this tributary had higher pH, alkalinity and total solute concentrations than other stations by 50 to 100%. This subcatchment is underlain by hornblende gabbro, which may weather more quickly than the granite bedrock which dominates the rest of the two basins.

Synoptic sampling in the Fever Brook watershed produced slightly different results. Elevated aluminum levels at the headwater site were only observed during snowmelt and storm events, and even under those conditions, no pattern of changes in pH with distance from the stream mouth was observed. During low and moderately high flows, aluminum actually increased slightly with distance downstream, reversing the pattern observed for higher flows. Silica did not exhibit any consistent spatial patterns, whereas sulfate, sodium and chloride decreased along the stream channel, which is opposite the pattern seen in the Swift River basin.

The results of regression analysis of stream water constituent levels for discharge dependency indicate that while the correlation was significant for hydrogen, all basic cations, and for alkalinity concentrations in the Swift River, only alkalinity demonstrated a significant correlation in Fever Brook. This lack of strong relationships for Fever Brook is due to the hydrological characteristics of the basin, which contained two large impoundments upstream of the gaging site.

ANALYSIS AND INTERPRETATION

By calculating net ion fluxes for the two watersheds it was determined that over 98% of the hydrogen load and about 96% of the nitrate load from wet deposition were retained through ion exchange reactions and nutrient uptake processes.

Over the course of this study, the combined load from mineral and carbonic acid in precipitation was approximately 1978 equivalents per hectare. Although total base cation export from both basins apparently exceeded this load, excess sodium from road salt cannot be considered part of the balance, because it is not a product of weathering. After the background sodium fluxes were estimated, the base cation loads generated in the basins were found to be 1780 and 1608 equivalents per hectare for Swift River and Fever Brook, respectively. Weathering and ion exchange may be said to neutralize 90% of the acid load to the Swift River basin and 81% of the acid load to the Fever Brook basin.

The remainder of the acid in the watersheds must then be neutralized through other mechanisms such as nitrate uptake by vegetation and alkalinity production by aquatic plants and micro organisms. Indeed, if it is assumed that virtually all of the carbonic acid load (estimated for -log PCO_2 = 3.5) was consumed in weathering reactions, then it may be concluded from the net fluxes for alkalinity that approximately 22.5 equivalents per hectare of additional alkalinity were generated in the Fever Brook watershed. Since this basin is dominated geologically by silicate minerals, with no significant geological sources of carbonate, it was concluded that 1) biological processes were the source of the additional alkalinity generated in the Fever Brook watershed, 2) these processes may be related to the prevalence of impoundments and marshes there, and 3) they can be a significant source of alkalinity.

The same (quite reasonable) assumptions applied to the Swift River suggest that 4.5 equivalents per hectare of carbonate alkalinity were consumed in the Swift River Basin or that about 1.8% of the estimated carbonic acid

load did not participate in weathering reactions, but was transported out of the watershed.

Extrapolation of these results for the prediction of long-term impacts and risk is a complicated matter. On the surface it appears that the capacity of the watersheds to neutralize acid precipitation was very slightly exceeded over the short time frame of this investigation. Such a conclusion, however, should not be drawn too hastily or with complete confidence. Firstly, it depends on an estimate of the proportion of sodium derived from mineral weathering versus road salt. (An attempt to corroborate this estimate with historical, geologic or other information is therefore warranted.) Secondly, the differences reported for the acid-base mass balances may be within the range of error inherent in and compounded by the various experimental methods used.

On the other hand, this study does indicate that acidification of streams tributary to Quabbin Reservoir is well within the realm of possibility, and that the risk of acidification of the reservoir itself, though not quantifiable, is undeniable. Already the chemistry of the two tributaries appears to be highly influenced by the deposition of strong acids. It is therefore reasonable and advisable to work toward source reduction even in the absence of quantitative risk evaluations or predictions of the future.

This study has also demonstrated the importance of meteorological, hydrological, geological and biological influences on water quality. Such knowledge of precipitation and watershed characteristics leads to improved experimental design for continuing monitoring and research. Indeed, a question that should not be overlooked is whether damage to the biological community from acid deposition may ultimately result in the degradation of water quality, since biological processes are found to constitute a significant portion of overall watershed acid neutralizing capacity.

<u>REPORTS</u>

"Effects of Atmospheric Wet Deposition on the Water Quality of Two Streams in the Quabbin Reservoir Watershed, Central Massachusetts, 1983-1985". USGS Water Resources Investigation Report (under review).

"Water Quality Hydrologic Data of the West Branch Swift River and East Branch Fever Brook, Quabbin Reservoir Drainage Basin" by R.L. Rittmaster and G.G. Girouard. USGS Open File Report (in press).

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE Hydrologic Controls on the Chemical Response of Streams to Precipitation Events in Central Massachusetts: Implications for Aluminum Mobility

AGENCY Department of Fisheries, Wildlife and Environmental Law Enforcement

PROJECT MANAGER Peter Oatis
Massachusetts Division of Fisheries and Wildlife
Field Headquarters, Westboro, MA 01581

PRINCIPAL INVESTIGATORS Richard Yuretich, Department of Geology, University of Massachusetts, Amherst, MA 01003

OBJECTIVES

The objective of this project is to determine the hydrologic and geochemical watershed conditions that effect the neutralization of acidic precipitation and the mobilization of various species of aluminum. Such understanding is necessary because previous work has indicated that the presence of toxic forms of aluminum associated with high levels of acidic deposition have had a serious impact on certain aspects of aquatic ecosystems.

METHODS

Networks for the intensive monitoring of hydrology and geochemistry have been installed in Cadwell Creek watershed on the western side of the Quabbin Reservoir (Pelham), and in Mundberry Creek watershed in Petersham. The selection of two separate sites within the Quabbin Reservoir watershed, which exhibit differing hydrochemistries, will enable comparisons and contrasts to be observed that might help delineate the specific conditions that govern the evolution of surface water chemistry. Parameters being measured include temperature, volume, and chemical measurements of precipitation, infiltration and interflow water, groundwater, and streamwater. Comprehensive analysis of the soils and surficial material for mineralogic and chemical characteristics is also underway.

Each monitoring network includes: a) collectors for sampling precipitation and throughfall composition; b) zero-tension lysimeters for obtaining water at three or four levels in the soil profile; c) a sampler for collecting interflow; d) several drilled observation wells for monitoring groundwater chemistry, of which one at each site is equipped with a continuous stage recorder; e) temporary weirs with continuous recorders for monitoring stream flow, and f) an electronic datalogger keeping track of hourly and daily changes in precipitation input, air temperature, stream and groundwater temperature, soil temperature and moisture content.

RESULTS

Data from the first 20 weeks have undergone preliminary examination. There are consistent differences between the Mundberry and Cadwell watersheds. Mundberry Creek tends to have higher pH (6.0 to 6.5), alkalinity and lower aluminum than Cadwell Creek (pH = 5.0 to 5.5). Similar patterns are noticed in the groundwaters, although the process of acquisition of chemistry in the subsurface is much more complex than originally envisioned. In general, Mundberry groundwater has a higher total dissolved solids content, especially with regard to calcium and potassium. Well-to-well variations during the same sampling interval can be very large in both watersheds, indicating that groundwater does not always move curvilinearly from recharge to discharge points. However, a predictable pattern of acid neutralization from shallow soils to deep soils to groundwater is usually observable, and we are now testing to see the seasonable variability in this process.

STATUS

Network installations were completed in fall 1987 and weekly samples are being collected. As of June 1, 1988, collections will be on a bi-weekly basis with additional samples collected during and after major precipitation events. All samples are being analyzed for pH, alkalinity, monomeric and total aluminum, and major cations and anions. This protocol will be continued through December, 1988.

Presentation

Quabbin Reservoir Research Symposium, May, 1987.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Stimulation of Mercury Methylation by Acid Deposition
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATOR	Cynthia C. Gilmour Harvard School of Public Health

OBJECTIVES

Methylmercury concentrations in the biota of acid-impacted freshwaters are often unacceptably high, even in lakes where inorganic mercury levels are low. Human ingestion of methylmercury in fish can be a serious public health problem, particularly to the developing fetus. Conversion of inorganic mercury to methylmercury, the form in which this metal bioaccumulates, is a microbial process which occurs in aquatic sediments. Recently, a specific group of anaerobic bacteria, the sulfate-reducing bacteria (SRB) have been identified as the primary methylators of mercury in natural sediments.

Because the metabolism of SRB in freshwaters is generally limited by sulfate concentrations, input of sulfate via acid precipitation increases sediment sulfate reduction rates. Rates are likely rise before a significant pH change has occurred in the water column or sediment. Thus, sulfate deposition "fertilizes" sulfate reduction and possibly mercury methylation by the SRB. A direct link between the metabolism of SRB and metal methylation rates explain elevated methylmercury levels in fish in acid-impacted lakes.

The objectives of this study are:

1. To test the hypothesis that sulfate deposition stimulates mercury methylation via the metabolism of SRB.
2. To begin to elucidate the mechanism(s) of microbial metal methylation.
3. To generate a model for mercury methylation rates in freshwaters based on indicators of sulfate reduction activity (e.g. sediment sulfide concentration or sulfate reduction rate) and data on sulfate deposition, water chemistry and mercury concentration in sediment and biota.
4. To gain a rough measure of the alkalinity generated via sulfate reduction in acid-impacted freshwater sediments.

METHODS

Studies will be conducted on three levels. Initial work is being performed at the microcosm level, exploring the influence of low levels of sulfuric acid loading on sediment sulfate reduction and mercury methylation rates. From these data, a rough model linking sulfate deposition to mercury methylation rate will be generated. The model will be extended to include other important parameters, such as inorganic mercury concentration and organic carbon loading, using existing field data from the Massachusetts Acid Rain Monitoring Project, Department of Environmental Quality Engineering and Division of Fisheries & Wildlife. Since Ontario has a very substantial data base on mercury levels in fish, these data may be included. After examination of the existing data, new measurements of field parameters indicative of sulfate reducing activity may be made as needed to support the model.

Studies on the mechanism(s) of metal methylation by SRB will be ongoing throughout the project. These pure culture physiological studies will help explain and support the empirical model for mercury methylation. SRB capable of mercury methylation are being screened for the ability to attack metal sulfides and for the production of extracellular metal binding and methylating agents. The eventual goal is to identify the methylating agents or enzymatic pathway(s) involved in methylation.

RESULTS

Pure culture studies All SRB cultures tested were capable of methylation of $HgCl_2$. Cultures tested include a number of morphologically and metabolically distinct cultures isolated in this laboratory and SRB from the American Type Culture Collection. It also appears that these organisms are capable of HgS methylation, although at a slower rate than $HgCl_2$ methylation. A study of the forms of Hg available for methylation is underway. Some of the SRB produce large quantities of exogenous material, and isolation and characterization of the metal binding capacity of this material is also ongoing.

Microcosm studies Sediments from Quabbin Reservoir are being used for this work. Sediments were collected at the outlet of a small stream, and are high in humic materials. Analysis of mercury and methylmercury levels in the sediments showed that while inorganic mercury levels are relatively low (about 10 ng/gm dry weight), the ratio of MeHg to Hg is very high, averaging 12%, but reaching 40%. Work from 1986 in sediments of the Hudson River, NY demonstrated that the ratio, MeHg/Hg, shows a strong negative correlation with free and acid-volatile (FeS) sulfide concentrations. Thus the percentage of Hg methylated tends to decrease with increasing salinity.

The low sulfide level and high percentage MeHg in Quabbin sediments fits a line extrapolated from the Hudson River %MeHg vs. sulfide profile. It seems that there is a balance between methylation activity by SRB and inhibition of that activity by sulfide, the product of sulfate reduction. This balance seems to drastically limit methylation in sulfidic estuarine and marine sediments, but it allows a high proportion of Hg to be methylated in freshwater sediments where low rates of sulfate reduction occur, but sulfide levels are relatively low.

STATUS

The project was initiated in July 1986 and will be completed in June 1988.

ANALYSIS AND INTERPRETATION

Inorganic Hg levels in the Quabbin sediments examined were reasonably constant (or decreased slightly) with depth, but MeHg showed a distinct peak just below the depth where sediments become anoxic, supporting the hypothesis that anaerobes produce methylmercury in freshwater sediments. MeHg levels were also strongly correlated with percent organic matter in the sediments. Work in Quabbin, along with the Hudson River study, suggests that sulfide controls methylation rate above some threshold level, and that sulfate reduction rate controls methylation below that level. Both sulfate deposition and availability of organic matter affect sulfate reduction rate.

The positive correlation between MeHg and organic matter in Quabbin sediments and the high %MeHg/Hg suggest that there is little inhibition of methylation by sulfide in this system. Work underway using Quabbin sediments in microcosms is attempting to define: a) levels of sulfate addition needed to stimulate mercury methylation and b) quantitative relationships between sulfate reduction, sulfide production and mercury methylation at low sulfate levels, such as those found in acid-impacted freshwater sediments.

Publication and Professional Presentations

Parts of this work have been included in the presentations and publications listed below.

American Society for Microbiology Annual Meeting, Atlanta, GA, March 1-6, 1987. Title: Mercury methylation by sulfate reducing bacteria in Hudson River sediments.

Dorset Research Laboratory, Ontario Ministry of the Environment, Dorset, Ontario, April 1987.

"Mercury in the Environment", a workshop sponsored by the Institute for Environmental Studies, University of Toronto, and the Ontario Ministry of the Environment.

This small workshop involved about 40 people who are actively engaged in research on mercury methylation, bioaccumulation and atmospheric deposition. CCG acted as "rapporteur" for the session on methylation processes and subsequently wrote a report for the OME summarizing the conclusions, current research topics, and future priorities identified by the group. The report should be available from the OME in fall 1987.

American Society of Limnology and Oceanography Annual Meeting, Madison, WI, June 15-19, 1987. Title: Uptake of tritiated thymidine by sulfate-reducing bacteria.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Role of Sulfate Reduction in Mitigating the Effects of Acid Deposition in Lakes
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter H. Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATORS	A. E. Giblin and B. J. Peterson The Ecosystems Center, Marine Biological Laboratory Woods Hole, MA 02543

OBJECTIVES

This project had two major objectives. One was to determine the importance of sulfate reduction in controlling the alkalinity of Cape Cod lakes by measuring the rates of burial of reduced sulfur in lake sediments. The second objective was to synthesize available data on the chemical composition of precipitation, lake water and groundwater on Cape Cod to determine which processes were most important in controlling the acidity of water in the Cape Cod Aquifer.

METHODS

We directly measured the storage of reduced sulfur compounds in lakes on Cape Cod. Bottom cores from six different lakes were analyzed for total sulfur, FeS, elemental S, and pyrite. In addition, we measured lead to estimate the sedimentation rate. We evaluated the potential capacity of lakes to continue to store sulfur in inorganic forms by measuring the concentration of Fe(II) and Fe(III). The importance of various processes to alkalinity generation or consumption as water enters and leaves Cape Cod lakes and groundwater was calculated by constructing a water budget and a cation and anion budget for the Cape Cod aquifer. We used available data from previous studies of the chemistry of precipitation (NADP), lake water chemistry (EMI and ARM) and groundwater (USGS), along with the known stoichiometry of reactions which consume or generate alkalinity, to estimate the importance of processes such as sulfate reduction, nitrate reduction and weathering on neutralizing acid precipitation as water moved through the Cape Cod Aquifer.

RESULTS

<u>Objective 1</u>

1) In some Cape Cod lakes up to half of the sulfur stored in the sediments is being stored as inorganic reduced sulfur, primarily pyrite.

2) In several Cape Cod lakes we have examined a large portion of the total iron in the sediments is tied up as ferrous sulfide minerals and iron may limit the capacity of these lakes to store reduced forms of sulfur as inorganic reduced sulfide.

3) In the range of lakes examined, the storage of reduced sulfur contributes anywhere from 20 to 160 mEq of alkalinity/m^2/year.

Objective 2

1) Both nitrate and ammonium are almost completely assimilated as they pass from precipitation to groundwater. The production of alkalinity from nitrate reduction outweighs by a factor of two the alkalinity consumed via ammonium uptake.

2) In the aquifer, the weathering of alumino-silicate minerals is the dominant process neutralizing the acidity of precipitation.

3) The sulfate/chloride ratio of rain and groundwater are very similar, indicating that the aquifer as a whole is not adsorbing or assimilating large amounts of sulfate. However, the sulfate/chloride ratio of lakes varies greatly, indicating that sulfate reduction may be a significant sink for sulfate in some lakes. Further analysis of the water chemistry data will take place this year with funding provided by the Cooperative Aquatic Research Program, Massachusetts Division of Fisheries and Wildlife.

STATUS

This project was initiated in July 1986 and completed in June 1987.

Presentations and Professional Publications

Controls on the burial of sulfur in lake sediments. To be presented at the 1987 ASLO Meeting at the University of Wisconsin-Madison, June 1987.

The role of sulfate reduction in mitigating the effects of acid deposition in lakes. Invited seminar presented at the Institute of Ecosystem Studies, Millbrook, NY, January 1987.

The role of sulfate reduction in mitigating the effects of acid deposition in New England Lakes - In prep. for submission to Limnology and Oceanography

AQUATIC EFFECTS

BIOLOGICAL IMPACTS

4 ABSTRACTS

BIOLOGICAL EFFECTS

Acidification and Fish Harvest Trends at Quabbin Reservoir - DFWELE

Physiological Stress Indicators in Fishes and their Potential for Application in Field Studies - DFWELE

Reproductive Failure due to Environmental pH and Ionic Factors in Landlocked Rainbow Smelt (Osmerus mordax) - DFWELE

Effects of Acid Precipitation and Breeding Strategies on Salamandar Communities in Massachusetts - DFWELE

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Acidification and Fish Harvest Trends at Quabbin Reservoir
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATOR	Richard Keller, DFWELE

OBJECTIVES AND METHODS

Quabbin Reservoir is an oligotrophic, 10,117 hectare impoundment located in the crystalline silicate rock terrain of central Massachusetts. Soils in the watershed are thin podzols developed on glacial till. The reservoir is managed by the Metropolitan District Commission (MDC) and serves as the main water supply for metropolitan Boston's two million people, and is one of the 72% of Massachusetts drinking water reservoirs that are sensitive to acidification (<10 mg/l total alkalinity). The Quabbin is Massachusetts' major cold water fishery and was ranked by the Massachusetts Division of Fisheries and Wildlife (MDFW) as the second most frequently fished water body in a 1984 statewide angler survey. Some 50,000 anglers a year harvest 25-30,000 kilograms of fish, primarily lake trout and smallmouth bass.

In recent years there has been concern for the impacts of acid deposition on Quabbin Reservoir. These concerns are derived from observations of: 1) declining catches of rainbow trout, 2) increasing egg mortality of smelt and 3) the replacement of bicarbonate with sulfate as the major ion. Sulfate levels have nearly doubled since the 1950's and are now on the order of 6.0 to 8.0 mg/l, while bicarbonate (alkalinity) has been reduced from 6.0 to 2.0 mg/l. Water provided to the Metropolitan Boston distribution system must be treated to reduce acidity and minimize dissolution of lead in city pipes. Treatment costs $1.3 million per year.

Some 60% of Massachusetts surface waters are classified as vulnerable to acidification (alkalinity < 10 mg/l) and 6% are acidified (alkalinity < 0.0 mg/l and pH < 5.0). Quabbin is the most extensively monitored of any of Massachusetts' waters. The Metropolitan District Commission has collected water quality data from 36 stations since 1956 at seventeen reservoir stations and nineteen tributaries. Three stations on the larger tributaries and one reser-

voir station have thirty years of weekly or bimonthly data. Precipitation has been recorded at Quabbin by MDC since 1930 and reservoir volume and discharge since 1939. The MDFW has collected fisheries data since 1950.

The rainbow trout fishery at Quabbin Reservoir was dependent on spring stocking of 228-305mm (total length) hatchery stock averaging 0.14 kilograms. Reproduction of this species in Massachusetts occurs in only a few small alkaline streams in western Massachusetts.) Major stockings occurred during two periods, from 1957 to 1961 and again from 1969 to 1984, and averaged 5000 and 15,000 fish per year respectively. Minimal sporadic stockings occurred in the interval between 1962 and 1968. Through 1979, the average return by number was estimated at twenty-three percent simply by dividing yearly return by number stocked. During the acid period of the 1980's, returns fell sharply (< 2.0%, 1983 stocking) and stocking of rainbow trout was discontinued in 1984 in favor of stocking more acid tolerant landlocked salmon.

A self sustaining lake trout population was established at Quabbin in 1961 from 10,000 fingerlings stocked in 1952 and an additional 260,000 between 1953 and 1957. Legal size fish (457mm T.L.) are produced in four to five years. Unlike rainbow trout where harvest is virtually unaffected by historical variations in reservoir pool elevation or volume, lake trout harvest is profoundly affected by changes in reservoir volume. Harvest of lake trout fluctuated concurrent with the major changes in water level elevation during and following the severe drought of the 1960's. (Yearly minimal pool elevation occurs approximately 50 days after lake trout spawning in mid November. The drop in reservoir pool elevation between lake trout spawning and yearly minimal pool elevation is less than 0.3 meters).

Adult rainbow smelt and eggs from Massachusetts coastal streams were originally stocked in Quabbin tributaries in 1953 to provide a forage base for resident salmonids. The importance of smelt to the sport fisheries is well documented. Spawning occurs in small tributaries in early April, rendering eggs and larvae vulnerable to acidic conditions from snow melt and spring rains. A high survival rate was characteristic of eggs deposited in these streams up until the late 1970's.

Largemouth bass, landlocked salmon and panfish harvest are unchanged. After seven years of increasing harvest, smallmouth bass harvest shows signs of a decline beginning in 1985. This decline is too recent to determine if increasing reservoir acidification may be involved.

The purpose of this paper is to examine the effects of acid deposition on Quabbin Reservoir. An analysis of the 29 years of weekly pH and alkalinity observations at four key stations within the Quabbin watershed are reported. Alkalinity levels are compared with historical variations in total precipitation. Trends in the harvest of rainbow trout and lake trout are examined relative to changes in water quality. The impact of acid deposition on smelt spawning is examined as are trends in metals levels within deep basin sediment cores.

RESULTS

Water Chemistry

Between 1956 and 1985, four episodes of low alkalinity were identified within Quabbin, followed by three episodes of increased alkalinity. Low alkalinity occurred during low precipitation episodes in 1956, 1963-64, and 1980 as well as during prolonged periods of above normal total precipitation in 1974-75 and the early 1980's (alkalinity recovered somewhat in 1981 after the 1980 low, but not as significantly as after the first three low episodes, and became low again in 1982-83). Differences between periods of low alkalinity and periods of high alkalinity are significant and occur during years where total precipitation is less than or exceeds the historical average precipitation (56 year mean) by one standard deviation or more.

In the West Branch of the Swift River, alkalinity changes in January and February were similar to those in the Quabbin, except the alkalinity peak associated with 1970 was more pronounced. Like the Quabbin, variations in alkalinity were associated with certain total precipitation events and only alkalinity peaks and lows are statistically different. The same significant patterns are evident in the variation of ANC in the Ware River diversion. Although the reservoir has a three year retention time, yearly changes in alkalinity within Quabbin's main tributaries and within the reservoir are occurring nearly in unison after 1960.

Historical variations in reservoir alkalinity cannot be explained by simple dilution from changes in reservoir volume. There is no significant correlation between change in yearly mean reservoir alkalinity and change in mean reservoir volume from one year to the next. Correlates of yearly average reservoir alkalinity are hydrogen ion concentration, calcium and magnesium (multiple r-square: 0.65) as opposed to reservoir volume and pool elevations above mean sea level. This suggests that the volume of the reservoir is presently not a major factor in buffering the system, and that reservoir and tributary alkalinity is largely dependent on watershed ANC generation.

Alkalinity peaks may represent periods of accelerated loss of the more soluble ANC generating mineral phases in the watershed through chemical leaching. Increased $H+$ ion loading which may occur during years of above normal, acid precipitation or the generation of soil water acidity due to the concentration of accumulated soil sulfate and exacerbation of the salt effect during droughts can be expected to cause increased dissolution of soil minerals. Oxidation of sulfur compounds as the water table is lowered may also generate acidity, leading to increased soil mineral dissolution. Alkalinity peaks occur with hardness peaks in the main tributaries.

This association is strongest in the West Branch of the Swift River. Alkalinity peaks always follow episodes of low reservoir alkalinity and increased reservoir acidity. Alkalinity peaks occurred in drought years in late 1964-1970 and in years of above average precipitation in 1959-60 and 1977-79 in both the Quabbin and its two main tributaries. Therefore, alkalinity peaks are poorly correlated with total precipitation and are not due simply to base flow conditions during droughts. Quabbin's alkalinity may be said to pulse

following episodes of low reservoir pH in association with hardness and alkalinity peaks in main tributaries. Therefore, alkalinity pulsing appears to be symptomatic of the acidification process producing episodes of accelerated chemical leaching.

The extent of strong acid weathering in any year can be quantified by comparing the alkalinity from carbonic acid weathering to the total dissolved base cations (sum of Ca^{++}, Mg^{++}, Na^{+} and K^{+}) from both carbonic acid and acid precipitation generated weathering (alkalinity-to-sum base cations ratios (ABC ratios). Quabbin reservoir's relatively low ABC ratios (0.08-0.29) indicate that watershed mineral weathering has been largely due to acid precipitation rather than carbonic acid weathering as far back as data exists (1950) with noticeably lower ABC ratios in the last decade. As expected, lowest ABC ratios correspond to historic alkalinity minima.

The occurrence of base cation peaks and alkalinity pulsing together with or shortly after alkalinity minima, and the relationship between the duration of the pulse and variations in total precipitation support the theory that alkalinity pulsing results from leaching of watershed minerals following increased dissolution during acid periods. The major determinates of reservoir chemistry are watershed soil water processes occurring long before the water reaches the reservoir. This is supported by observations of: 1) the poor correlation between yearly changes in reservoir volume and changes in reservoir alkalinity, 2) variations in main tributary and reservoir alkalinity occurring in unison even with a three year reservoir retention time and 3) the minor difference in reservoir and main tributary alkalinity (generally less than 1 mg/l).

Higher ANC values, due likely to low flows and increased biological production, occur during the warmer months of June to August. From 1978 on, however, summertime alkalinities drop sharply and are no longer distinguishable from spring and fall periods. This suggests a possible reduction in microflora ANC production within the river and soils of the watershed, a possible consequence of increased aluminum toxicity.

Episodes of alkalinity peaks in Quabbin represent a temporary recovery of buffering capacity as peaks occur between episodes of ever more severe alkalinity minima. Rather than representing a true recovery, alkalinity pulsing represents a net loss of watershed ANC measured in terms of the difference in alkalinity between preceding and following alkalinity minima. Alkalinity pulsing masks the decreasing ability of the watershed to generate ANC. Long term trends in surface water alkalinity at Quabbin are therefore better determined by trends in alkalinity minima which measure system ANC during periods of acid stress and reflect the loss of watershed ANC occurring during the intervening alkalinity pulses.

A temporary recovery of reservoir ANC from the early 1980's lows (by pulsing) is possible. The duration, frequency, and severity of low alkalinity periods can be expected to increase and ultimately result in an acidified reservoir if sulfate loading is not reduced. The historical pattern of alkalinity suggests that declining alkalinities should resemble a negative sloped sine wave of decreasing amplitude. It is not possible to predict when a zero alkalinity event in Quabbin will occur, as alkalinities are dependent on the rate of watershed ANC deterioration and precipitation events. Using the trends

in reservoir alkalinity minima as a measure of watershed ANC deterioration, there is an increased probability of a zero alkalinity event after the early 1990's.

Reservoir alkalinities in the early 1980's began to pulse following the 1980 low precipitation event. Above normal precipitation in 1981-82 appeared to terminate the pulsing process. The alkalinities in the early 1980's, the lowest on record, are in actuality the product of opposing forces: higher then normal total precipitation, much of it acidic, and watershed ANC pulsing. Had the precipitation in the early 1980's and alkalinity pulsing occurred out of phase, the Quabbin's alkalinity may well have dropped much lower then it actually did. Periods of zero alkalinity will be associated with significant pH depression followed by partial recoveries. Loss of sensitive aquatic species in the food chain, such as smelt, and the disruption of fish reproduction during low pH periods will harm the ecosystem as the reservoir progresses towards acidification.

Rainbow Trout

Variations in alkalinity associated with periodic low and high precipitation periods appear to play an important role in rainbow trout survival, as average yearly reservoir pH minima and maxima are associated with alkalinity minima and maxima. Yearly averaged pH's during alkalinity minima may not reflect conditions existing during critical periods. The pH below 50 feet during the alkalinity lows of the early 1980's was as low as 5.4 in the lower hypolimnion in late August. In the deeper southern end of the reservoir, containing seventy percent of the August cold water fish habitat, aluminum levels below the thermocline may reach 0.2- 0.3 mg/l for short periods of time during late summer. The elevated aluminum levels can react synergistically with marginally suitable pH to make the water quality less favorable to rainbow trout survival.

Chemistries unfavorable to rainbow trout may occur at the mouths of acidic tributaries and within associated coves in the reservoir during spring and fall runoff when reservoir alkalinities are at or near seasonal lows. In the spring of 1981, a number of rainbow trout were observed dying within Cadwell Creek cove coincident with a heavy rain. Following a sharp decline in rainbow trout harvest in 1981 and 1982, an investigation was made in the spring of 1983 into possible low pH and elevated metal induced mortalities.

Hatchery reared rainbow trout and landlocked salmon from stocks traditionally liberated in Quabbin were placed in inert plastic coated wire cages (five 125-254mm fish per cage) at the mouths of acid impacted tributaries and within associated coves (pH: 4.5-5.5, total aluminum: 0.2-0.4 mg/l). Cages were provided with plastic upstream v-shaped current deflectors and were anchored to the bottom substrate by wooden stakes. Control fish in identical cages were placed in non-acid-impacted Quabbin tributaries and in hatchery raceways (pH: 5.7-6.1, total aluminum: 0.05-0.1 mg/l). (Raceway fish did not experience transportation stress.) All caged fish placed in acid streams and coves died within two to four days. Gills were heavily clogged with mucus. All control fish appeared unaffected and were released at the end of two weeks. Results clearly indicated the potential for substantial stress or mortality when rainbows attempting to spawn are attracted to acid impacted tributaries and associated coves during spring runoff.

Lake Trout

Lake trout harvest is predicted by reservoir volume at recruitment (four years prior to year of harvest) for years when reservoir pool elevation is more than two meters below the spillway (161.5 meters msl). Reservoir elevations or volume the year of harvest were poorly correlated with harvest ($r = 0.41$). The ability to predict lake trout harvest based on reservoir volumes four years previous is consistent with historical age and growth data. Lake trout reach legal size at IV+ and this year class makes up a sizable fraction of yearly harvest. A sharp reduction in predicted harvest occurs at reservoir levels between 3.0 and 4.6 meters below spillway.

The 1984 harvest is one third less than predicted based on reservoir volume. In 1980, the year of recruitment, the onset of the most acid period in the reservoir begins in conjunction with the low precipitation period of 1980. This acid period continues with the high precipitation period of 1981-84. Reservoir capacity at recruitment averaged 81% for six years prior to 1984, thereby effectively removing reservoir volume as a major factor affecting the 1984 harvest. During the early 1980's, after six years of increasing lake trout harvest and releases, harvest begins to decline sharply. Any possible impact of acid deposition on lake trout recruitment must, therefore, be recent (after the late 1970's).

Hydrogen ion concentration at recruitment (negatively correlated with sublegal lake trout catch) explained 90% of the variation between reservoir chemistry and sublegal lake trout catch. The number of sublegal lake trout in the catch declined steadily from 1979 to 1985 (50% reduction) followed by a decline in the catch of legal lake trout beginning in 1983-84. The significant negative correlation of hydrogen ion concentration with the year of sublegal lake trout recruitment suggests that the degradation of watershed ANC has progressed to the point where lake trout reproduction is being impacted coincident with reservoir alkalinity minima.

Rainbow Smelt

Smelt egg mortalities in Quabbin tributaries ranging from an estimated 20 to 90 percent, between April 22 and 27, 1983, were associated with 3.86 cm of precipitation with an average pH of 4.21. Smelt egg mortalities were less than one percent before the rains in Hop Brook and Northeast Hop Brook on April 22, 1983 (historically, two of the more consistently used smelt spawning streams) and fifty to seventy percent after the rains on April 27th coincident with a drop in pH from 6.4 to 5.4.

The average pH of eight west arm streams and nine east arm streams during the 1983 smelt spawning period was 4.9 and 5.5 respectively. In 1984 estimates of egg density and mortality were made in four tributaries using randomly placed artificial spawning substrate. Egg mortalities ranged from 18 to 43% in association with elevated aluminum concentrations of 0.1 - 0.2 mg/l. High smelt egg mortalities have also been observed in the absence of aluminum and at a pH between 6.3 - 6.7 in Underhill Brook and at several other tributaries at Quabbin when nickel was present at 0.08 to 0.13 mg/l in 1985 and 1986.

Infrequent shoal spawning of smelt has been reported, but its importance in maintaining the smelt population is believed to be significant. An extensive area of egg deposition (1220 sq. ft.), involving a small stream and shoal spawning, occurred on the east arm of Quabbin in 1985. In-stream egg mortality was estimated at 70% in association with a pH of 6.08, total aluminum of 0.13 mg/l and calcium of 3.31 mg/l. Egg mortality within a 100 foot wide cove associated with the stream was 100 percent. At 200 feet beyond the mouth, egg mortality was one percent. At this location pH was 6.17, calcium: 2.59 mg/l and aluminum was below the detection limit of 0.02 mg/l. Of fourteen spawning tributaries with a history of smelt egg deposition since at least 1973, six have had no egg deposition since 1980, two have had no evidence of spawning since 1982, and six have current runs associated with 20-90% egg mortality depending on the timing, amount, and acidity of precipitation occurring during the runs.

Mobilization of Metals and Wildlife Implications

Aluminum is the third most abundant element within the earth's crust and is widely present in soils. It is believed that the strong mineral acids from acidic deposition can mobilize this soil aluminum. Evidence of this mobilization lies in the elevated aluminum levels in Quabbin's tributaries (0.1-0.4 mg/l). The watershed flux of aluminum into the reservoir may be as high as 40-80 tons/yr. As the pH of the reservoir is generally still above 6.0, much of the mobilized aluminum can be expected to precipitate out of solution onto the reservoir bottom. This process of watershed mobilization and in-reservoir precipitation may have been going on for twenty years or more.

Sediment cores were taken in 30 meters of water in both reservoir arms near Winsor Dam and Goodenough Dike in 1985. Cores were divided into thirds and analyzed for several metals including aluminum. The top third of the cores (7.6 centimeters) contained 17,500 to 19,100 mg/kg of acid soluble aluminum (dry wt.). This core depth represents detrital deposition over approximately the last 10 to 15 years. These concentrations represent a doubling or tripling of aluminum in sediments within that time.

It appears that aluminum is remobilized from the sediments into the water column. In samples taken in August, 1985, within 10 meters of the bottom, total aluminum concentrations ranged from 2.26 to 3.25 mg/l and concentrations of 0.12 to 0.34 mg/l occurred up to the top of the thermocline. Above the thermocline, concentrations ranged between 0.0 to 0.08 mg/l. Calcium levels dropped rapidly while aluminum concentrations increased within 30 feet of the bottom.

It is possible that a significant fraction of the sediment aluminum might be remobilized into the water column should the bottom pH fall to 5.0. The threshold of toxicity of monomeric aluminum to fish in poorly buffered surface waters is 0.1-0.2 mg/l. Sublethal concentrations of aluminum have been shown to cause histopathological changes in fish organs and to interfere with reproductive physiology in trout. Any widespread remobilization of sediment aluminum can be expected to interfere with fish reproduction and may cause fish kills dependent on the type of aluminum and final concentration after mixing. A possible avoidance reaction by fish to elevated aluminum levels occurred at Winsor Dam in 1985. No lake trout or other fish were found near the Dam as indicated by sonar tracings made during the traditional lake trout spawning

period of mid November, although this area has excellent spawning habitat and had been consistently utilized by spawning lake trout from 1965 to 1979.

The increase in aluminum in sediment cores suggests widespread watershed soil disturbance by excess mineral acids. An important consequence of this disturbance can be an increase in a variety of heavy metal levels in upland vegetation and wildlife. Tree cores were taken from two white pine (Pinus strobus) growing on the banks of two acid impacted tributaries at Quabbin (Cadwell Creek and Cobb Brook) to investigate the possibility of elevated metal concentrations. Results revealed an increase in aluminum and vanadium levels after 1962, periodic peaks in arsenic levels in the late 1950's and early 1980's, and a decrease in lead levels after 1976. The increase in aluminum and vanadium after 1962 is about the same time that the base cation levels began to increase in the reservoir.

An analysis was made of the liver and flank tissue of an adult white tailed deer taken from the Cadwell Creek watershed. Liver cadmium was five times higher then normal. While such results are preliminary and cannot be extrapolated to the Quabbin watershed at large, they are supported by other studies. Cadmium has been shown to increase in vegetation in acidified habitat.

During 1971-1976, mercury levels above the Massachusetts drinking water standard of 0.2 ug/l were periodically observed in the surface waters (1 meter depth) of Quabbin ranging from 0.01 ug/l to 300 ug/l with mean values of 0.1 to 39.2 ug/l. Values exceeding 0.2 ug/l were typically observed in May and June (Wallace and Floyd Associates 1983). The period 1971-1976 coincides with reservoir volume recovery following the 1960's drought, and it is reasonable to assume that the excessive mercury concentrations are the result of mercury bound to resuspended particulate matter.

In 1985, an immature bald eagle which had been hacked at Quabbin in 1983 on a diet consisting mainly of Quabbin fish was recovered in New York state sick and unable to fly. The bird was sacrificed to end its suffering when it did not improve after several months at the United States Department of the Interior's Laboratory. Severe mercury poisoning was indicated by elevated blood levels. It is not known for certain where the eagle picked up the mercury. The possibility exists that it may have been at Quabbin.

There has been an increase in mercury levels within the last 10-15 years as indicated by two sediment cores taken in deep water at the southern end of Quabbin. This increase may be due in part to resuspension following reservoir volume recovery in the 1970's and in part to an increase in mercury input into the reservoir. Recently, sulfate-reducing bacteria (SRB) have been identified as the primary methylators of mercury in surface waters. A direct link may exist between increased sulfate deposition, increased SRB metabolism and increased methylmercury (the form in which the metal bioaccumulates) in poorly buffered waters. Analysis of mercury in Quabbin's fish is in progress.

ANALYSIS AND INTERPRETATION

The increasing severity of reservoir acidity since 1980 has necessitated elimination of the stocked rainbow trout fishery. Increased mortality of smelt eggs in Quabbin Reservoir tributaries is occurring during spring spawn-

ing because of low pH and elevated aluminum levels. Eight of fourteen traditional smelt spawning streams have had no evidence of egg deposition since 1982. Lake trout harvest declined from 1983 to 1985.

The evidence presented in this report indicates that the reservoir is progressing towards acidification. Predicting when Quabbin might actually acidify (pH < 5.0) is difficult, as acid periods are related to trends in total precipitation, including twenty year drought cycles and unexpected years of exceptionally high rainfall. Further complicating the picture is the inability to predict the duration of alkalinity pulsing.

The reduction in lake trout harvest and loss of rainbow trout has been mitigated in part by stocking the more acid tolerant landlocked salmon. Shore spawning of smelt is believed to be maintaining the smelt population, and coupled with an increasing dependence on Asellus, is maintaining lake trout condition factors. Increasing acidity, elevated aluminum and decreasing alkalinity and calcium levels can be expected to ultimately result in the loss of the smelt forage base. Disruption of lake trout and smallmouth bass reproduction can be expected coincident with decreasing reservoir pH. A significant remobilization of bottom sediment aluminum appears a plausible future event should the bottom pH fall to < 5.0.

The increased mobilization of heavy metals in acid impacted watersheds and the subsequent bioaccumulation of metals in fish and wildlife may be one of the more serious consequences of air pollution and associated acid deposition. Metals may impair physiological functions of fish and wildlife as well as render fish and wildlife unfit for human consumption. Increasing levels of metals in the environment may also impact human health. There are virtually no data on metal concentrations in wildlife in acid impacted areas of Massachusetts. Evidence of increased metal mobilization at Quabbin points to the need to determine metal levels in fish and wildlife in acid impacted watersheds statewide. Localized remobilization of sediment aluminum in the deepest basins of Quabbin underscores the need to map the location of sediment aluminum in drinking water reservoirs vulnerable to acid deposition and to understand the factors controlling remobilization and aluminum speciation during a mobilization event.

REPORT

Keller, R. L. (1987) Acidification and Fish Harvest Trends at Quabbin Reservoir. Massachusetts Division of Fisheries and Wildlife.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE Physiological Stress Indicators in Fishes and their Potential for Application in Field Studies

AGENCY Department of Fisheries, Wildlife and Environmental Law Enforcement

PROJECT MANAGER Peter Oatis
Massachusetts Division of Fisheries and Wildlife
Field Headquarters, Westboro, MA 01581

PROINCIPAL INVESTIGATOR Paul Kostecki, University of Massachusetts

OBJECTIVES AND METHODS

Use of indices of stress in fishes is an ongoing issue of contention. Laboratory scientists, field biologists and fish culturists all realize that serious consequences result whenever fish live under conditions which exceed the limits of their adaptive mechanisms. Recognizing signs of stress and identifying their cause(s) are critically important in determining appropriate corrective measures to alleviate stress. It is hoped that stress-related research may provide response-specific indicators for particular sets of environmental conditions suitable for use in the field.

This paper investigates the possibility of identifying a sub-lethal indicator of stress associated with increasing acidity. This indicator could then be used as a major criteria in determining when to employ mitigative liming practices.

From a practical standpoint the problem is choosing the most appropriate indicator for a particular stress and/or a particular situation. An ideal indicator would be:

- o sensitive
- o fast
- o accurate and repeatable
- o inexpensive
- o applicable to field, lab or hatchery
- o applicable to a variety of species
- o stressor specific

Although no present methodology encompasses all of these, several approaches have been developed. Simple techniques, such as differential white blood cell counts, are invaluable in assessing the overall health of higher vertebrates. The potential exists for adapting a similar technique for fish. More complicated analyses, such as tracking stress-induced immunosuppression, are applicable to piscine physiology. Other techniques to indicate stress

responses in fishes include a variety of biochemical assays and indices, examination of mucoidal microfauna composition and degree of epidermal mucification, and behavioral toxicology, as well as the more traditional method of precise measurement of growth, which may be useful as a general indicator of stress. However, no technique has been proven to be stressor specific.

Fish physiology is highly complex, encompassing many disciplines, and fish health assessment is a rapidly expanding, dynamic field of research. Enormous amounts of literature have been devoted to keeping pace with progress made over the last 5 - 10 years. For those interested in pragmatic uses of this information, a systematic evaluation of current methodologies and data is much needed.

It is the intention of this report to provide the user with the basic physiological principles and concepts necessary for an understanding of how a stressor, such as environmental acidification, may impact fishes (Physiology of Stress section). In addition, a description and evaluation of some of the techniques which have been used to attempt to quantify stress in fishes (Stress Responses and Indicators section) is provided, along with a discussion of the potential of developing a specific indicator for environmental acidification.

RESULTS AND STATUS

Physiology of Stress

The concept of "stress" refers to the response of an organism to an environmental stimulus, and always involves a negative impact of the environment upon the organism. Factors external to the system influence the internal state of the system. In stress research, systems may be defined at the cellular, tissue, organismal, population or ecosystem levels. "Stress" represents negative deviations from the norm, degrading system integrity and lessening the likelihood of survival. In terms of energetics, systems increase their energy expenditure to maintain themselves in the face of environmental stressors.

"Stressors" are the stimuli that cause the system state of stress. By definition stressors are external to the system they are impacting.

The study of stress physiology examines organismal responses to nonfavorable environmental factors. Stress may affect fish populations in two general ways, causing either direct mortality or decreased performance capacity. Research on stress physiology is particularly relevant to fisheries management and aquaculture, as the impacts of stress have widespread and important implications in both fields.

Fisheries management deals with "wild" (i.e. noncaptive) fish stocks. Stress may have severe impacts on wild stocks, resulting especially in increased susceptibility to predation. Reproduction appears to be more sensitive to stress than adult survival. Fecundity and egg viability are directly affected by many environmental stressors, and in cases of extreme stress gonad resorption occurs prior to spawning. Even if hatching is successful, stressors may cause recruitment failure.

Aquaculturists deal with captive fish stocks where stress can affect both the quantity and quality of fish. Disease outbreaks are a major concern to culturists and stress has been shown to play a key role in susceptibility to disease.

Environmental factors can be categorized according to their effects on an organism. Lethal factors, for instance, destroy the integrity of an organism. Controlling factors influence rates of metabolism by their effects on levels of molecular activity. Limiting factors influence metabolic rates by restricting the supply or removal of components of metabolic pathways. Masking factors modify the operation of other factors. Directive factors influence organisms through the transduction of environmental signals into internal information.

The influence of an external biotic or abiotic factor is mediated by an organism's internal state. That is, the same factor can have different impacts on the same system at different system states. An organism's age, sex, nutritional status, etc. all affect the degree of influence environmental factors have.

Stressors may be specific or general. Specific stressors elicit particular responses which are not normally generated by other stressors. They tend to affect specific biochemical pathways. Pesticides, for example, have been shown to affect highly specific enzymatic pathways. General stressors affect a wide range of physiological processes. They elicit stress responses which are nonspecific. A wide variety of different stressors may cause similar physiological responses in the organism.

The specific physiological mechanisms by which particular stressors impinge on organisms are often not clearly understood. The distinction between specific and general stressors may actually be one between stressors that act directly through the central nervous system and those that do not. General stressors may cause information to be sent to the central nervous system before a physiological stress response occurs. Specific stressors may go undetected by the central nervous system until they act directly on biochemical pathways.

The duration and intensity of a stressor have critical implications for the severity of a stress response. Typically stressors are classified as acute or chronic. Acute stressors are short lived with fairly high levels of intensity. Chronic stressors tend to be low level with fairly long durations. The distinction between acute and chronic is somewhat subjective. The definition of intensity is always relative to the response it induces. Stress responses are mediated by many factors. Thus the assessment of stressor intensity can be highly contextual.

The definition of normalcy is a key problem in stress physiology. The very nature of physiological systems requires that the definition of normalcy is always relative. The distinction between stressed and normal systems is often based on circular logic. Stressed systems are defined as nonnormal. Normal systems are defined as unstressed. Furthermore, organisms may change their normal ranges of variance over time and space through adaptation and acclimatization.

Stress Responses and Indicators

The impact of stress on fishes may be manifested in a variety of ways, but not all physiological changes associated with stress are of equal impact. Hence interpretation of the significance of a given indicator must be assessed with caution. The responses exhibited by fishes to stress can be subdivided into primary, secondary and tertiary responses.

A) Primary responses:

These are largely changes in the circulating levels of key endocrine compounds. They include additional secretion of:

1) ACTH (adrenocorticotropic hormone) by the adenohypophysis, 2) epinephrine and norepinephrine from chromaffin tissue, and 3) corticosteroids from interrenal tissue. A wide variety of stressors result in indistinguishable primary responses.

B) Secondary responses:

Physiological changes at this level usually require hours to days to become apparent. The duration of secondary responses is longer lasting than primary responses, but they are initiated by the more transient endocrine changes outlined above. Included here are a variety of changes in blood chemistry, including hyperglycemia, hyperlactemia, hypochloremia and hyponatremia. Other changes include decreased clotting time, a fall in the number of circulating white blood cells, and shifts in the ratios between white blood cells.

C) Tertiary responses:

Symptoms shown at this level of stress response are the longest lasting, yet the most difficult to quantify. Included here are reproductive impairment, elevated mortality after additional stress, decreased growth and conversion ratios, immunosuppression and increased susceptibility to disease altered behavior or migratory patterns, and inhibited parr-smolt transformation.

Primary Response Indicators

The catecholamines epinephrine and norepinephrine are sometimes referred to as the "stress hormones" in fish. The presence of any stressor is likely to result in elevated levels of epinephrine or norepinephrine in circulation, although which of the two predominates may be species specific and sex specific.

Much research has been conducted to investigate the role of corticosteroids in the stress response. It is now recognized that cortisol and other glucocorticoids have largely inhibitory effects. These include negative feedback mechanisms suppressing the release of ACTH (the pituitary hormone triggering the release of corticosteroids) and corticotropic release factor (CRF) (the hypothalamic hormone regulating the release of ACTH).

Significant difficulties and uncertainties exist in attempting to use these compounds as stress indicators. There is a lack of conclusive research evaluating their usefulness as indicators of acid stress.

Secondary Response Indicators

A number of potential secondary stress indicators are reviewed, including blood glucose, free fatty acids, Liver Somatic Index (LSI), DNA/RNA ratio, metallothionein, liver enzymes, Adenylate Energy Charge, lactate, red blood cells, and white blood cells. The same limitations apply to indicators at this level when applied to acid stress.

Tertiary Response Indicators

Many authors have stressed the need for incorporating analyses of tertiary-level symptoms of stress in assessing fish health. Such studies, however, require long-term commitment to research and are not, at this time, amenable to use as field indicators of stress. A detailed discussion of tertiary-level stress indicators is beyond the scope of this report.

ANALYSIS AND INTERPRETATION

The concepts underlying stress and stress indicators in fishes are extremely complex, and their practical application is very general in nature. Thus, the idea of one stressor/one response and vice versa is not easily realizable.

A review of the literature suggests that there is an absence of research on stress indicators in fishes which are specific to environmental acidification. Most work on specific stressors has had to do with pesticides, which tend to affect specific biochemical pathways. Although much is known about the physiological responses in fishes exposed to acid conditions, the same level of mechanistic detail is lacking.

Most stress work has focused on general stress indicators. The problem is that most stressors elicit responses which are nonspecific. Thus, similar physiological responses may result from a wide variety of different stressors. For example, reduced acidification has been shown to significantly decrease the liver somatic index (LSI) in laboratory experiments with brook trout, by reducing the weight of the liver. Further, it appears the reduction in LSI is more sensitive than measuring just body weight loss. It has been suggested that the reduction in liver weight is due to a reduction in energy stores within the liver as the animal utilizes more energy for regulation in the face of environmental stress.

Other factors, both environmental and biotic, such as temperature, season, food supply (abundance and type) and sexual maturity, would also impact the LSI. Thus, the LSI's utility as a field indicator of past or present levels of acid-stress is questionable unless an extensive amount of information is known. For a proper assessment, a detailed bioenergetic model would be required for each population or species. This model would need to be developed from detailed water chemistry, dietary, and population dynamics data as well as statistically representative LSI's. A modeling effort of this enormity would require a multi-disciplinary, multi-year project.

The LSI may also be useful from an environmental health standpoint to predict a fish population's ability to withstand an environmental perturbation such as acidification and provide a fisheries based sensitivity index. This is predicated on the fact that the LSI in some species is a relative index of energy stores which would be available to the animal for the regulatory responses involved in adaptation to environmental change.

With respect to the remaining stress indicators discussed in this paper, a major weakness for their use as acidification stress indicators is a lack of experimental data relating them directly to acid stress. Therefore, a proper evaluation of their potential as acid stress indicators is impossible at this time.

Methodologies other than traditional stress indicators may warrant further investigation. Specifically, a pH challenge test similar to the sea water challenge test developed for assessing the physiological state (Smoltification) of salmon smolts may prove useful. The sea water challenge test in salmon is used to determine the readiness of underyearling salmon for entry into sea water. The test utilizes plasma sodium concentrations in fish exposed to full sea water and is based on the ability of salmon smolt to regulate their plasma levels within 24 hours after transfer. The purpose of the test is to determine whether these fish are physiologically capable of surviving in sea water even though they are being held in fresh water.

The rationale behind a pH challenge test is that fish may be physiologically capable of tolerating certain pH ranges based on past exposure history, which is known to modify acid tolerance in fishes. Comparison of specific responses with respect to some physiological parameter such as blood $Na+$, which has been shown to be affected by acid stress, could prove useful.

REPORT

"Physiologicasl Stress Indicators in Fishes and Their Potential for Application in Field Studies" by S. Belle, K.R. Byrne and P.T. Kostecki. Water Resources Research Center Publication No. 155, University of Massachusetts, Amherst. February, 1987. 59 p.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Reproductive Failure Due to Environmental pH and Ionic Factors in Landlocked Rainbow Smelt (Osmerus mordax)
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATOR	Paul Kostecki, University of Massachusetts

OBJECTIVES AND METHODS

Acidic deposition has become a serious environmental concern in the United States, Canada, and Scandinavia. Numerous scientific publications have documented the acidification of lakes and streams in these countries with resultant damage to fish and other components of aquatic ecosystems. At current rates of emissions of sulfur and nitrogen oxides, the numbers of European and North American lakes and their fish populations affected by acidic deposition can be expected to more than double by 1990.

The Northeast region of the U.S., and New England and Massachusetts in particular, have been identified as regions highly susceptible to acid deposition. In addition, hydrogen ion (H+) loading information indicates that the New England states are most prone to surface water acidification. Many of the larger lakes in New England have significant populations of salmonids whose primary food source is freshwater smelt. These potadromous forage fish ascend small feeder streams during the early spring to spawn. However, some lakes in New England have shown a decrease over the last few years in the number of streams ascended by smelt. In the Quabbin Reservoir in Massachusetts, smelt now spawn in only two or three streams whereas 15 years ago they reportedly spawned in eleven tributaries. Since rainfall and snowmelt have been shown to be highly acidic, especially during the smelt spawning season, it has been suggested that the disappearance of smelt in some tributaries is related to the problem of environmental acidification.

The lethal effects of environmental acidification on fishes are well established. Although acidification has been shown to result in mortality, it more commonly effects reproduction. Most of the evidence for fish extinction in acid water indicates reproductive failure. Reproductive failure may occur on the individual level as spawning cessation, but is probably more significant at the population level in the form of recruitment failure. Recruitment failure in fishes has been attributed to mortality of eggs and larvae at low

pH. A number of species have been investigated in this area, but no published works exist quantifying the effects of environmental acidity on egg and larval survival in smelt, an important forage-base fish.

Probably the greatest weakness in our knowledge of the effects of environmental acidity on smelt concerns how water quality factors modify response. The importance of such modifying factors has been well established for other species with two of the more important factors being external calcium and aluminum concentrations. When calcium concentrations are low, fish populations tend to disappear from lakes at higher pH than when calcium concentrations are high. Environmental aluminum concentrations also have been cited as important in determining the effect of environmental pH. Fish mortality in some acidic waters has been attributed to both environmental pH and metal concentrations. Aluminum concentrations may be additive to the detrimental pH effects and alter the level at which mortality occurs.

It was the purpose of this study to establish the effect pH has on the survival and hatching of rainbow smelt eggs, and to determine the degree to which calcium and aluminum ion concentration modify the response.

Eggs and milt were stripped from randomly selected individuals of a population of 62 adult landlocked rainbow smelt, Osmerus mordax, seined from tributaries of the Wachusett Reservoir, Massachusetts on April 10, 1985. The experimental treatments included all possible combinations of three levels each of Ca^{2+} (0.5 ppm, 1.0 ppm or 2.5 ppm), Al^{3+} (0.1 ppm, 0.25 ppm or 0.5 ppm) and pH (4.3, 5.3 or 6.3), i.e. 27 different test solutions were prepared. In addition, each possible combination was run in triplicate. The pH was raised or lowered to the desired level by the dropwise addition of 0.1M HCl or 0.1M NaOH. Solutions were unbuffered. Each container was individually aerated and immersed in a "Living Stream" water bath maintained at 6.9 C + 0.87 (x + S.D.) for the duration of the experiment.

Three experimental parameters were measured: "Percent Hatch" - the proportion of the starting number of eggs in each environment which lived to hatch during the experiment, "Percent Survival" - the proportion of the sac fry which, upon hatching, lived in the particular experimental treatment for 24 hours, and "HT50" - the time, in days, necessary for 50 percent of the total number of hatchlings in any given environment to emerge. All values were calculated as means of pooled data from each available replicate of each test environment.

Homogenous degrees of standard deviation for percent hatch and percent survival were achieved by an arcsine transformation of the data. Similarly, a square-root transformation was applied to HT50 counts. Such transformations improve the degree of satisfaction of assumptions such as those of normality and equal variances and, simply, make the variances independent of the means.

RESULTS

The individual effects of pH and Al^{3+} as well as their two-way interactions all have significant ($p < 0.05$) impacts on the percentage of eggs which hatched in the experiment. Hatching success is generally proportional to the pH level and inversely proportional to the aluminum ion concentration over the

given experimental ranges. All experimental levels of aluminum were detrimental to egg survival at all but the lowest levels of pH; at pH 4.3 there is a slight increase in hatching success with incremental changes in Al^{3+}.

The level of calcium ion alone was not found to have any statistically significant influence over hatching success nor was a highly significant interaction found between Ca^{2+} and Al^{3+}. A statistically significant two-way interaction was found, however, between the calcium ion level and the pH. This trend is only marginally significant and may only reflect the enormous importance of pH previously described.

The concentration of aluminum ion and its two-way interaction with pH significantly influenced the percent survival of smelt sac fry. The analysis was complicated by differential rates of hatching success (0.2-50.5%) and a protracted hatch-out period (20 days). Thus, it was impossible to quantify the initial 24-hour survival of sac fry from a single, consistent baseline value.

Data from this experiment and others imply that fish eggs need not necessarily be subjected to the test environment throughout their embryological development to obtain meaningful results. Thus, it may be possible to reduce the variance apparent in the percent survival parameter by measuring survival as a separate test from percent hatch. For example, day-old hatchlings from a common pool of fry raised from a single batch of eggs (methodology which should favor hatching synchrony) can easily be pipetted into test environments in exact numbers to allow for a more rigidly-controlled analysis.

As in percent hatch, percent survival was inversely proportional to the aluminum ion level over the given experimental ranges.

Some studies have shown a tendency for enhanced survival of fish embryos when Ca^{2+} is added to low pH environments. The present study supports the hypothesis that calcium plays a role in mitigating acid stress in smelt eggs prior to hatching.

Statistically, Ca^{2+}, Al^{3+}, pH and all of their possible two-way interactions have significant impacts on HT50. The HT50 was calculated because daily observation revealed that eggs in high aluminum environments appeared to lag in development by up to a week relative to eggs in other test solutions but not in time of hatching. Therefore it is conceivable that eggs under high aluminum ion stress were, in effect, hatching prematurely. This contention is supported by their correspondingly low percent survival. A more satisfactory approach to support (or refute) this hypothesis would be to quantify the time necessary for the median number of embryos to reach critical developmental stages (e.g., blastulation, gastrulation, neurulation, "eyeing", etc.). Such a detailed investigation was well beyond the scope of this study though future work along these lines may provide valuable information.

ANALYSIS AND INTERPRETATION

The data support the hypothesis that changes in environmental conditions in streams related to acid precipitation may decrease viability of rainbow smelt eggs. Although some level of viability occurred for all experimental conditions, it appears that ecologically important levels of viability would not occur at pH = 4.3. Further, the presence of aluminum ions would exacerbate the deleterious effects of altered pH. However, calcium ion concentrations appear to have a mitigating effect with respect to pH and this suggests that liming of streams when smelt spawning occurs may be effective in protecting those populations.

REPORT

"Reproductive Failure Due To Environmental pH and Ionic Factors in Landlocked Rainbow Smelt (Osmerus mordax)" by P.T. Kostecki, K.R. Byrne and E.J. Calabrese. Water Resources Research Center Publication No. 150, University of Massachusetts, Amherst. December, 1985. 30 p.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Effects of Acid Precipitation and Breeding Strategies on Salamander Communities in Massachusetts
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters; Westboro, MA 01581
PRINCIPAL INVESTIGATORS	Scott D. Jackson and Curtice R. Griffin, University of Massachusetts, Amherst, MA 01003

OBJECTIVES

There is concern that some species of amphibians, such as mole salamanders (Family Ambystomatidae), may be declining in New England. Potential factors leading to declines may include overcollecting, toxic chemicals such as pesticides, loss of breeding habitat, acid deposition, and in the case of Jefferson complex salamanders (Ambystoma jeffersonianum, A. laterale, A. platineum, A. tremblayi), breeding strategies. This study is investigating two of these threats to salamander communities in Massachusetts, acid deposition and breeding strategies.

The objectives of the research are:

1. To assess the effects of acid precipitation on reproductive success for mole salamanders in the Connecticut Valley of Massachusetts.

   a) Determine the distribution and status of spotted (A. maculatum), Jefferson (A. jeffersonianum) and silvery (A. platineum) salamanders in the Connecticut Valley in relation to pond chemistry.

   b) Determine rates of embryonic mortality for mole salamanders in relation to pond chemistry.

   c) Evaluate historical changes in salamander reproductive success in relation to changes in pond chemistry.

2. To Assess the effects of breeding strategies on reproductive success of Jefferson complex salamanders in the Connecticut Valley.

   a) Determine the structure, size, sex ratio, and reproductive success of a select population of Jefferson complex salamanders.

b) Evaluate whether male Jefferson salamanders distinguish between diploid and triploid females of the complex, and whether preferential mating occurs.

METHODS

Egg masses of spotted and Jefferson complex salamanders from 14 ponds were monitored to determine hatching success. These are the 13 ponds studied by Cook (1978, 1983) in 1976 and 1977, plus a large breeding pond in Westfield, MA. Water samples were taken from the ponds and analyzed for a variety of chemical constituents. Hatching success was then evaluated in relation to pond chemistry to determine whether acid precipitation is affecting egg mortality. Results of this study will be compared with those of Cook (1978, 1983) to evaluate historic trends.

A drift fence was used at the Westfield site to determine the structure, size, sex ratio, and migration phenologies of a large breeding population of Jefferson complex salamanders. Controlled breeding experiments conducted in the field under natural conditions were used to determine whether male Jefferson salamanders can distinguish between their own females and female silvery salamanders, and whether preferential mating occurs. Eggs laid by females involved in breeding experiments were monitored to determine reproductive success.

RESULTS

Water Chemistry

Analyses of rain water and weekly water samples from each of the 14 ponds indicate that acid precipitation can have significant short term effects on pond chemistry. Heavy spring rains combined with snow meltwater produced drops in pH from 6.0 to 5.3 in one pond and from 4.8 to 4.5 in another. During this same period of time monomeric aluminum levels increased dramatically; some ponds registering increases of 43 to 355 percent. Given that monomeric aluminum has been linked to mortality in fish, these increases could potentially influence salamander egg mortality.

Comparisons of all ponds at a given time indicate a strong negative correlation between monomeric aluminum and pH. However, this correlation is not apparent when looking at any particular pond over time. This may indicate that levels of monomeric aluminum in the ponds fluctuate more closely with rainfall than pond pH, or that other chemical constituents may be effecting aluminum levels.

Egg Mortality

Results from two years' data (1986 & 1987) indicates that egg mortality varies widely from pond to pond and from year to year. Egg mortality by pond ranged from 5 to 48% for spotted salamanders, and from 5 to 23% for Jefferson complex salamanders in 1986. Data from 1987 have not been fully tabulated yet, but indications are that those ponds which demonstrated high mortality in

1986 did not experience high mortality in 1987. In addition, two ponds which experienced low mortality in 1986 had much higher mortality in 1987.

Based on 1986 data, egg mortality does not appear to be correlated with pond pH. A possible connection does exist between mortality and monomeric aluminum (which is correlated with acid deposition). Egg mortality also appears to be positively correlated with both color and dissolved organic carbon, indicating a possible role for naturally occurring organic acids. Research and analyses will continue though next year.

Breeding Strategies

Estimates taken from direct counts of animals collected by drift fence at the Westfield pond indicate the breeding population of Jefferson complex salamanders at this site to have been 726 animals in 1986 and 560 in 1987. In both years males accounted for 13% of the population of Jefferson complex salamanders. Males of the spotted salamander made up 70% of the population in 1986 and 60% in 1987, at this same site. Comparison between species indicate that male Jefferson salamanders are relatively rare, a situation which could have adverse effects on reproductive success for Jefferson complex salamanders at this site.

Results of the breeding studies have been inconclusive so far. Research will continue through next year.

STATUS

This project was initiated in September 1985 and will be completed in June 1988.

Professional Presentation

"Assessing Effects of Acid Precipitation on Salamander Communities".
Presentation at the 1986 Northeast Nongame Technical Committee Meeting, Seaville, NJ.

AQUATIC EFFECTS

MITIGATION

6 ABSTRACTS

MITIGATION

Mitigative Lake Liming - DFWELE

Physical, Chemical and Biological Impacts of Liming on a Cape Cod Kettle Pond - DFWELE

Ecological and Chemical Responses of Whetstone Brook during Continuous Treatment with Calcium Carbonate - DFWELE

A Preliminary Economic Assessment of Liming Acidified Lakes and Ponds in Massachusetts - DFWELE

Investigation of Forest Management Impacts on Watershed Hydrology and Aquatic Chemistry - MDC

Biological Monitoring Program, Dickey Brook Watershed, Quabbin Reservoir, 1985-1986 - MDC

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE Mitigative Lake Liming

AGENCY Department of Fisheries, Wildlife and Environmental Law Enforcement

PROJECT MANAGER Peter Oatis
Massachusetts Division of Fisheries and Wildlife
Field Headquarters, Westboro, MA 01581

PRINCIPAL INVESTIGATOR Living Lakes, Inc.

OBJECTIVES

In partial fulfillment of its responsibility to protect and maintain the Commonwealth's freshwater fishery resources, the Division of Fisheries and Wildlife (DFW) has been developing and evaluating various mitigative strategies for the protection of aquatic resources. To facilitate investigation of lake liming as a means of mitigating the effects of acid rain on critically sensitive lakes, DFW sought and received a Generic Mitigative Liming Permit through MEPA. DFW then entered into an agreement with Living Lakes, Inc., a non-profit organization funded by utilities as a means of demonstrating lake liming as a fish restoration strategy in acid impacted lakes. Under this agreement, Living Lakes, Inc. assumes responsibility for essentially all of the costs of liming lakes in Massachusetts selected with the cooperation of the DFW.

METHODS

Lakes are selected for liming based on a set of criteria including physical and chemical characteristics, the availability of suitable fish habitat and food resources, and the history of fish populations within the lake. Pretreatment baseline data collected from selected sites include water quality, fisheries, aquatic habitat characteristics, watershed soils and geology, lake morphology, precipitation, and site and watershed usage. Most of this data is derived from the databases of state agencies, and supplemented where necessary by on-site measurements.

Treatment is accomplished by adding calcite ($CaCO_3$) to restore pH and acid neutralizing capacity (ANC) to pre-acidification levels. Application amounts and methods depend on site accessibility and the pre-treatment data gathered as above. Limed lakes are then monitored three times per year after treatment for various water quality parameters and once per year for fish populations for a period of five years.

RESULTS AND STATUS

Eight Massachusetts ponds were limed by the project in 1986, all but one in the southeastern part of the Commonwealth. Four additional ponds were limed in 1987.

Initial results indicate that target goals for water chemistry, specifically pH and alkalinity, can be achieved accurately, and that the integrity of the trout fishery potential can be maintained. The length of duration of the beneficial effects of liming and the positive and negative impacts of liming will be assessed at the end of the five year study period for each lake.

The project is ongoing and is on schedule, with minimal expense to DFW. At least three more ponds are planned for liming in 1988. Further results will be forthcoming as data analysis continues.

ANALYSIS AND INTERPRETATION

While only a temporary measure, liming can be effective in mitigating the impacts of acid rain and restoring the cold water fishery in certain lakes and ponds. The expense of liming can be significant for a program of this sort. To date, Living Lakes has invested over $1,100,000 in the Massachusetts Mitigative Lake Liming Project.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Physical, Chemical and Biological Impacts of Liming On a Cape Cod Kettle Pond
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATORS	Betsy Colburn and Ann Shortell Massachusetts Audubon Society

OBJECTIVES AND METHODS

This study was designed to evaluate any immediate and longer-term impacts of liming on the physical, chemical and biological aspects of a Cape Cod kettle pond. The study was initiated in 1984, the year prior to the re-liming of Great Pond, Truro, Massachusetts, in order to establish baseline conditions from which to evaluate the effects of lime addition to Great Pond. Ryder Pond was monitored concurrently as a reference.

Both ponds are typical Cape Cod kettle ponds, fed by seepage from the Wellfleet groundwater lens of the Cape Cod aquifer and by atmospheric precipitation. They are similar in size and depth and both are surrounded by scrub oak and pine. The two ponds differ in management history, however. Ryder Pond has not been actively managed, while for three decades Great Pond has been extensively managed as a sport fishery. The pond was limed in 1973 (1 ton/ha). In 1983 Division of Fisheries and Wildlife (DFW) personnel proposed liming Great Pond for a second time, because pH and alkalinity measurements suggested marginal conditions for fisheries.

Prior to 1983, DFW had conducted small scale liming activities as part of its trout management program for two decades. In 1983 DFW proposed expansion of the liming program in response to evidence that many Massachusetts waters were poorly buffered and potentially sensitive to damage from acid deposition. The majority of the waters initially targeted for liming were in the south-eastern part of the state and on Cape Cod. Although scientists and fisheries managers agree that liming is only a temporary measure against the effects of acid rain, it may be the only means possible of partially protecting particularly sensitive aquatic ecosystems until the levels of atmospheric sulfate and nitrate are reduced.

The two ponds were monitored for a variety of physical, chemical and biological parameters on a near monthly basis from January, 1984 to October, 1986. Sampling took place at the deepest points of each pond. Physical parameters included temperature profiles, light transmission, transparency, and apparent color. Samples were collected for chemical analysis at one meter below the surface and one meter above the bottom. Chemical parameters included pH, alkalinity, acidity, calcium, chloride, hardness, and dissolved oxygen. Biological work included extensive sampling and identification of zooplankton (tow samples and discrete depth samples, from one meter and one meter above the bottom), as well as sampling and identification of benthic invertebrates and some phytoplankton sampling and identification. Fish were sampled annually by DFW and macrophytes were mapped and identified annually.

In March, 1985, DFW applied six tons of agricultural limestone to Great Pond. This rate of approximately 500 pounds per acre is one half the dosage added in most ponds. The amount was reduced because the bottom waters of Great Pond become anoxic during the summer months. DFW also stocked Great Pond with 1500 trout in April, 1985, although this was not part of the study design.

RESULTS

Physical Characteristics

Great and Ryder Ponds are both dimictic, although in Ryder Pond the thermocline moves deeper in the water column throughout the summer, eventually extending to the bottom. Light transmission and transparency are greater in Ryder Pond, which may account for its greater warming in summer. Transparency decreased significantly following liming in Great Pond. Color in both ponds was generally low, with the exception of late summer, 1984, when color was dramatically higher in both ponds. Color was generally somewhat higher in Great Pond, although an increase in color was not observed following the liming event.

Chemical Characteristics

Both Ryder and Great Ponds are soft water lakes for which salt water spray is a major source of ions. Water chemistry is generally quite similar in the two ponds, with the exception of higher calcium levels in Great Pond.

The water chemistry parameters related to pH and buffering (alkalinity, hardness) were significantly increased by the addition of lime in Great Pond. It is anticipated that these effects, with the possible exception of calcium concentration, will gradually return to pre-March 1985 conditions in Great Pond, which were not significantly different from Ryder Pond at the time. Indeed, the most recent sampling events already show some reduction in pH. On the other hand, residual effects of previous lime addition persisted at Great Pond. Calcium concentrations in Great Pond did not return to unlimed levels even after 12 years, but by Spring, 1984, pH levels were below 5 and some of the fish populations exhibited signs of stress. Elevated calcium concentrations appear to help mitigate the stress associated with low pH.

Biological Effects

Effects on the biota have been subtle with the exception of acute effects on the plankton immediately following liming. This is not unexpected for the following reasons:

- Great Pond had been limed previously.
- The lime addition was half that which is typically applied.
- While pH and alkalinity were low prior to liming, fish recruitment was still occurring.
- Toxic metal concentrations in the lake were and are low.

Some species shifts and biomass suppressions have occurred. Analyses of these changes are continuing. The potential for significant decreases in zooplankton and benthic invertebrates should be of concern to biologists managing liming/stocking programs, because of their value as a food source. Trout stocked in the year of liming were in extremely poor condition in the year following liming. While fish recruitment is likely to improve after liming, zooplankton are likely to be scarce as a food source, which may partially account for the starved condition of the stocked trout in Great Pond. This condition could also lead to a potential decline in trout sport fishing there. A time lag of at least one year between liming and stocking provides some time for resource adjustment and recovery after liming.

ANALYSIS AND INTERPRETATION

Liming and stocking must be carefully coordinated to achieve the highest benefits of each fisheries management strategy. In addition to stocking issues, the decision to lime involves monetary considerations. Although some changes in lake chemistry may persist for years after liming, liming is generally considered a mitigative strategy which must be repeated to be effective. Most resource managers would prefer to lime as infrequently as possible.

The decision to lime lakes where toxic metal concentrations are low is often made on the basis of pH and alkalinity. Calcium is an important factor modifying species distributions, however, and some evidence suggests that low pH is not as detrimental to aquatic organisms when calcium levels are not too low. Elevated calcium concentrations may persist at protective levels even after pH declines. This may permit the safe delay of subsequent liming for a period of time at substantial monetary savings for statewide programs.

We recommend that seasonal sampling continue to document long-term trends, and reversal of liming effects. These data will be necessary to make scientifically sound long term management decisions. In addition, more effort should be undertaken to document any benefits to the fish populations, such as increased growth rates or increased recruitment.

REPORT

"Physical, Chemical and Biological Impacts of Mitigative Liming on a Cape Cod Kettle Pond" by A.B. Shortelle and E.A. Colburn. Final Report for Massachusetts Division of Fisheries and Wildlife. September 1987.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Ecological and Chemical Responses of Whetstone Brook During Continuous Treatment with Calcium Carbonate
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	David B. Halliwell Peter Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATOR	Kenneth R. Simmons Massachusetts Cooperative Fisheries Research Unit University of Massachusetts, Amherst, MA 01003

OBJECTIVES

The study objective is to determine the ecological and chemical changes that occur in Whetstone Brook during a continuous, long-term liming program. The goals of the liming program are to raise the pH of the stream to 6.5 and alkalinity to 50 ueq/l for a distance 3.16 km downstream of the doser.

Problem

Data from Phase I of the Massachusetts Acid Rain Monitoring Project (ARM I) indicate that 36 percent of the state's surface waters are "endangered" (i.e., alkalinity less than 100 ueq/l $CaCO_3$) by acid precipitation. These waters include over 100 streams with important fishery resources (MDFW, unpublished data). In order to meet its mandate to "protect and enhance fisheries" in these streams, Massachusetts has chosen to participate in the USFWS Acid Precipitation Mitigation Program (APMP) to gain information on the environmental impact, cost, and technology associated with mitigative stream liming. In general, the Acid Precipitation Mitigation Program was established to provide information on ecological responses to the mitigative liming of surface waters impacted by acid deposition, and to provide guidance for resource and fisheries managers responsible for protecting the Nation's inland fisheries. This Massachusetts research effort complements similar APMP projects in Tennessee, West Virginia, and Minnesota.

METHODS

The following APMP site selection criteria were used for screening candidate sites:

Programmatic: annual average wet deposition pH of less than 5.6 units, which is the major factor posing risk to system; a pH of less than 6.0 units or an alkalinity of less than 50 ueq/l occurring during critical life history periods; stress in fish populations not attributable to point-source pollution or fishing pressure.

Hydrologic: average annual flows greater than $0.2 m^3/sec$ and maximum mean monthly flows less than $25\ m^3/sec$.

Research: target area at least 3 km in length without confounding morphometric features; no natural or point-source toxic metal contamination; aquatic chemistry dominated by natural acidity; apparent color < 75 PCU or dissolved organic carbon (DOC) concentration < 4.5 mg/l; fish habitat must be suitable.

Confounding Factors: well-defined drainage basin; undisturbed watershed; accessibility for monitoring; security from vandalism; value as a representative natural resource; lack of recent chemical manipulation in stream or watershed. Note: Whetstone Brook was closed to fishing in March, 1986 for the duration of the five-year APMP project.

Whetstone Brook, a 6.8 km long, second-order tributary to the Millers River within the town of Wendell, was selected as the APMP study stream. Located within the Central Highland physiographic region of Massachusetts, Whetstone Brook drains $5.22\ km^2$ with an average gradient of 22.9 m/km. This cold-water stream currently supports populations of brook and brown trout, in association with American eel. Forage fish species (e.g., blacknose dace), present in Whetstone Brook in the 1950s no longer occur. Data indicate that there has been an increase in the acidity of Whetstone Brook over time, coincident with a decline in the fisheries. It is believed that acidification is the cause of the fishery decline, since fishing pressure is low and there have been no major physical changes in the watershed.

Study Hypotheses

A. Pre-liming water quality conditions in Whetstone Brook does not affect mortality of trout during spring runoff.

B. Base addition to Whetstone Brook does not:

(1) Affect physical parameters, including sediment pH
(2) Affect nutrient levels, or concentrations of toxic metals
(3) Raise acid neutralizing capacity (ANC) and pH
(4) Buffer acid pulses from snowmelt or precipitation
(5) Affect standing crops of phytoplankton as indicated by the concentrations of chlorophyll a
(6) Affect mortality of trout during spring runoff
(7) Affect recruitment and growth of resident trout
(8) Affect the structure and population size of fish and invertebrate communities.

The APMP research design involved sectioning the study area into stream segments (chemical sampling units) and stream reaches (biological sampling units), based on field reconnaisance and preparation of a stream gradient

profile. The 3.71 km study area on Whetstone Brook was sectioned into four segments and seven reaches. Two permanent tributaries were also identified and included in the study design. Reaches were selected to represent typical habitats and include a low-gradient spawning area in both the control (reach A) and treatment (reach E) segments.

Discharge is continually recorded on a USGS flow gauge installed downstream of the target area on Whetstone Brook. Chemical and physicochemical sampling is conducted monthly (bi-monthly during high flows) on four mainstem stations and on the two permanent tributaries.

Sampling for fish and invertebrates is conducted within six mainstem reaches. Invertebrates are sampled seasonally using a Surber (n=6) and kick-net (n=3) sample collected at random from stratified locations in riffle habitat. A single random search (one-hour) of all habitats in a reach using a variety of methods is conducted.

Fish sampling to determine species composition, population data, biomass, and age and growth is conducted in early fall, while fish recruitment sampling is done in the late spring. Multiple electrofishing runs (n=2-4) are used in concert with block seines placed at the upstream and downstream boundaries of permanent 75 m sample stations within each mainstem reach (A-F).

Pre-liming and operational in situ fish bioassays are conducted both within the control and treatment areas on Whetstone Brook, as well as on a nearby non-acid-impacted stream (Jacks Brook, Erving).

RESULTS

Average monthly USGS discharge data on Whetstone Brook ranged between 0.03 m^3/s (Sept. 1986) to 0.82 m^3/s (Jan. 1986), while the annual average for December 1985 to November 1986 was 0.30 m^3/s. Discharge measurements made during August and September indicate that the flow at the dosing site is 48% of the flow at the target endpoint. Discharge from tributaries A and B contribute 22% and 6%, respectively, to the mainstem flow in Whetstone Brook.

Chemical data have been collected since April 1986. Tributary A is well-buffered in contrast to either the mainstem or tributary B. Average pH on Whetstone Brook for the period of record ranged between 5.6 and 6.0, and total alkalinity ranged between 31 and 38 ueq/l $CaCO_3$. In contrast, tributary A pH and alkalinity average values were 6.4 and 54, whereas tributary B average values were 5.4 and 9 ueq/l, respectively. High sulfate levels associated with low calcium and high monomeric aluminum are found in the acidic tributary, but the inverse is true for the more fertile tributary and the mainstem of Whetstone Brook. Excessive dissolved organic carbon levels in the mainstem reflect beaver activity which has subsequently been curtailed through trapping.

Preliminary observations of invertebrates collected to date indicate that total biomass and species richness are low.

Fish sampling was conducted in late-October, mid-May and early-September. In 1985 there were relatively few individuals in the 100-150 mm size class for

both species, suggesting high mortality among the 1983-1984 year class. In 1986 there was an increase in the number of fish captured in this size class, suggesting higher survival of the 1984-1985 year class. Age and growth analyses will be conducted to confirm these observations.

Brook trout appear to dominate the upper control reach, while brown trout biomass increased downstream through the study reaches. Though low, trout abundance and biomass increased from 1985 to 1986. Estimated population sizes for brook and brown trout in Whetstone Brook are low, in both the control and the treatment reaches. Fish recruitment success was qualitatively evaluated during the spring of 1986. Young-of-the-year trout ranged in size from 27-57 mm and were most abundant within the spawning reaches both in the control (A) and the target reaches (E).

ANALYSIS AND INTERPRETATION

Results to date, descriptive of pre-liming conditions only, show that the Whetstone Brook system is complicated by the presence of two permanent tributaries which have differing water quality characteristics. The additional buffering capacity of tributary A and the acidic input of tributary B tend to factor out, resulting in similar water quality conditions on Whetstone Brook above and below these drainages. Additional studies need to be conducted to characterize geomorphology within the study area.

In conclusion, pre-liming chemistry data indicate acidic water quality conditions in Whetstone Brook, and fish populations appear stressed as reflected in low species diversity, small biomass and poor year-class survival. Operational stream liming will commence during early summer 1988 and continue through the fall of 1990.

Whetstone Brook in Wendell is one of the many streams in Massachusetts endangered by the deleterious impacts of acid deposition and needful of mitigative protection. Actual costs of doser purchase, installation, and maintenance plus material are estimated to run in the vicinity of $50,000/stream treated on an operational basis.

Until Congress passes legislation to reduce emission of the precursors to acid deposition, the MDFW is forced to rely on mitigation to carry out its mandate. Even if legislation is passed in the near future, severely impacted surface waters may require mitigation for many years to protect fish stocks.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	A Preliminary Economic Assessment of Liming Acidified Lakes and Ponds in Massachusetts
AGENCY	Department of Fisheries, Wildlife and Environmental Law Enforcement
PROJECT MANAGER	Peter Oatis Massachusetts Division of Fisheries and Wildlife Field Headquarters, Westboro, MA 01581
PRINCIPAL INVESTIGATOR	David B. Rockland, Director of Economics, Sport Fishing Institute

OBJECTIVES AND METHODS

A recently completed statewide survey (the Acid Rain Monitoring Project) indicates that approximately 40 percent of the inland waters in Massachusetts are highly sensitive (alkalinity less than 10 mg/l) to adverse environmental impacts associated with cultural acidic deposition. Roughly 20 percent are classified as critical or acidified, with less than 2 mg/l and 0 mg/l alkalinity, respectively. The loss of biological productivity, especially fish, is well documented for acid sensitive waters in both North America and Europe.

In Massachusetts, the Division of Fisheries and Wildlife (DFW) is responsible for protecting and enhancing the inland fisheries resources. In fulfillment of this responsibility, the Division has recently developed a mitigative liming policy to address the potential acidification problems encountered at all lentic waters classified as critical or acidified. To date, the addition of limestone has proven to be the most practical means of restoring and/or preserving threatened fisheries habitat from the impacts associated with increasing acidification.

The development of a cogent liming policy requires the collection and judicious integration of a broad spectrum of interrelated ecological, social and economic fishery resource data. The nine step liming decision pathway incorporated by the policy requires data on all of the above fishery aspects.
The ninth step states that the treatment must be cost effective.

The intent of this paper is to provide an initial economic assessment of our liming strategies at critical and/or acidified lakes in Massachusetts and to develop a break even point below which net benefits derived are not cost effective. The data used to develop these assessments were obtained from creel and angler characteristic surveys of Massachusetts inland anglers conducted by both the State DFW and the United States Fish and Wildlife Service.

This initial economic assessment was conducted by evaluating the costs of liming in relation to the projected economic benefits. The economic concepts used to calculate benefits were economic impact and economic value, which represent alternative ways of evaluating the economic benefits of liming.

As related to a fishery resource, economic impact refers to the change in economic activity (e.g. output, employment, income) generated in the economy as a result of the resource use (in this case the recreational use of a lime-maintained fishery). Economic impact is considered to be the sum of the direct impacts (the initial purchases made by the recreational fishermen) plus the indirect and induced impacts resulting from these initial purchases. For the purpose of this analysis, total economic impact was calculated as the sum of all sales and income taxes generated from the purchases of equipment and supplies by recreational fishermen. Several other minor sources of tax revenues would result from retail expenditures, such as taxes on gasoline, but sales and income taxes account for the vast majority.

The alternative type of benefit calculation, economic value, is designed to represent the value that people place on the resource (in this case the opportunity to fish in limed fisheries). Economic values can include user value (the value placed on use of the resource by its various users), option value (the value that individuals place on the option to use the resource at some point), bequest value (the value of endowing the resource to others, especially future generations), and existence value (the value to society associated with the existence of the resource). Because option, bequest and existence values are difficult to quantify, economic value is represented herein by user value alone.

User value is a measure of the users' willingness to pay for the goods or services consumed in the process of using the resource, and generally includes some amount over the amount actually paid. In this report user value is determined by the net willingness to pay (NWTP), also known as the consumer surplus, which is the difference between the amount the user would have been willing to pay and the amount actually paid (the total value minus the purchases). Applied to a fishing trip, the NWTP represents the amount in excess of actual expenditures that the average angler would pay before foregoing the trip.

Each of these two types of economic benefit were compared to the economic costs of liming (calculated as the cost per acre times the number of acres limed). The benefits were calculated in each case as the average benefit per angling trip times the number of trips on an annual basis. The expected number of trips was calculated as a function of the available fish stock. For each benefit type, two scenarios were evaluated - one in which no liming was done and acidification caused fish populations to decrease (and eventually die out), and one in which liming resulted in the maintenance of stable, healthy fish populations. Relevant assumptions were made concerning fish catch rate, average fish weight, lake productivity (pounds of fish per acre), and fish mortality rate. For the no liming scenario, it was assumed that acidification would prevent reproduction; the fish population therefore would decline due to fishing and natural mortality. As participation in recreational fishing is assumed to be directly dependent upon the number of fish available, the number of fishing trips (and hence economic benefit) also would decline annually in the absence of liming.

A hypothetical 100 acre pond was used in a model calculation of economic benefits and costs. A computer program was used to compare benefits and costs over ten years. The analysis sought to determine how long a given application of lime had to effectively maintain the fish population for liming to be economically viable (i.e., the number of years the economic benefits of the limed fishery had to accrue before meeting the initial cost of liming). All dollar figures used in this report are expressed in 1985 dollars.

RESULTS

The average total expenditure per fishing trip in Massachusetts was determined to be $11.95 from a 1984 survey of licensed anglers conducted by the DFW. This figure was then used in conjunction with an economic model of the state of Massachusetts (prepared by the Department of Commerce) to calculate the total economic impact (direct, indirect and induced combined), in terms of the sales and income tax revenues generated by these expenditures. By these calculations, an average of $0.95 in tax revenues is generated by each fishing trip.

Based on a study by the U.S. Department of the Interior and another study by the U.S. Forest Service, the NWTP for a day of trout fishing in Massachusetts was set at $10.98. This then was used as the economic value benefit amount per fishing trip.

The hypothetical 100 acre lake used in this study would be capable of producing enough fish to support 1,120 angler trips per year, based on the assumptions made about fish catch rate, fish weight, lake productivity and fish mortality. For this number of trips the economic impact benefit is $1061 ($0.95 x 1,120) in tax revenue for the year. The economic value benefit (NWTP) is $12,298 for the year ($10.98 x 1,120). These two figures represent two different ways of evaluating economic benefits.

[It is very important to note that these are very simple and preliminary estimates for the purpose of assigning rough benefit/cost ratios. A more complete analysis would look at a myriad of other factors.]

The current cost of liming a lake in Massachusetts is approximately $70 per surface acre. For the hypothetical 100 acre lake used in this analysis, the liming cost would be $7,000.

Under the no liming scenario, both the economic impact (tax revenue) and economic value (NWTP) benefits decline each year as the fish population declines, reaching levels near zero by the sixth year, as calculated by the computer program. With liming, the economic benefits are assumed to remain the same year after year, as the fishery resource is maintained by the beneficial effects of the lime. In other words, with liming, the state continues to receive $1,061 in tax revenue from the fishery each year and anglers continue to experience $12,298 in benefits from the use of this resource.

The difference between the benefits accrued each year with liming and the benefits accrued in the absence of liming were then calculated and referred to as the cumulative benefit of liming. After seven years the cumulative differ-

ence in economic impact (tax revenue) between the liming and no liming scenarios would total nearly $7,000, or approximately the original cost of the liming. At this point the benefit/cost ratio is approximately one. Seven years is then the break even point for this hypothetical liming project, in terms of economic impact. For the state treasury to receive back the $7,000 originally spent, the neutralizing effects of liming would have to last for seven years, under this example.

From an economic value (NWTP) perspective, the cumulative benefits of liming would outweigh the costs, even after one year. According to this analysis, people would value the recreational opportunity maintained by the liming in excess of the liming costs, regardless of how long the liming is effective.

This preliminary economic assessment of liming in Massachusetts is now complete.

ANALYSIS AND INTERPRETATION

Generally, the mandate of a government is to create benefits for the people it represents. In the case of liming acidified waters in Massachusetts, this analysis shows that the economic value people assign to the benefits they receive through liming exceeds the costs. Also, revenues accrue to the state treasury from the fishery that is maintained and help defray costs. If the neutralizing effects of liming last seven years or more, the costs to the state become totally defrayed as the amount paid into the treasury equals or exceeds the amount paid out to undertake the liming.

Liming appears to make economic sense in Massachusetts, based on this very limited and preliminary analysis. However, it is very important to be aware that the analysis is preliminary and that the data were only applied to a hypothetical 100 acre pond. A more complete analysis would involve the actual fishing waters considered for liming and determine the efficacy of liming operations at those sites.

<u>REPORT</u>

A Preliminary Economic Assessment of Liming Acidified Lakes in Massachusetts by D.B. Rockland and P.H. Oatis, Massachusetts Division of Fisheries and Wildlife, 1986.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Investigation of Forest Management Impacts on Watershed Hydrology and Aquatic Chemistry
AGENCY	Metropolitan District Commission
PROJECT MANAGERS	Alfred Ferullo (former), MDC Joseph McGinn and Karen Eager, MDC
PRINCIPAL INVESTIGATOR	Jeffrey Strause, USGS

OBJECTIVES

A six-year study is being conducted to evaluate the effectiveness of forest management in increasing yield to the Quabbin Reservoir and to observe any impacts on aquatic chemistry and biology, particularly with respect to the fate of atmospheric deposition derived acids. The immediate objectives are to determine the rainfall-runoff characteristics, describe the chemical characteristics of precipitation, surface water, and groundwater, and to develop an evapotranspiration budget for two small tributary subbasins, before undertaking selective clearcutting in one of these subbasins. This project was conducted concurrently with a two year biological monitoring effort.

METHODS

Project Site

The two watersheds which comprise the project site are subbasins of Dickey Brook, which is located on the Prescott Peninsula of Quabbin Reservoir. The subbasin selected for forest clearing is referred to as the experimental basin. The second subbasin will serve as a study control basin. Control basin data will be used as a baseline for evaluating trends in hydrological budgets or deposition rates when comparing pre- and post cutting conditions in the experimental basin.

The control subbasin has a contributing drainage area of 1.24 square miles, of which about 4 percent is wetlands. The experimental subbasin has an area of 1.08 square miles, with roughly 15 percent wetlands. Data on the quantity and quality of precipitation, stream water, and ground water have been collected for both basins since February, 1985.

Beginning in the late fall of 1986, 100 acres (0.16 square miles) of pine forest in the experimental basin were cleared. Although this area represents only 14.5 percent of the total basin area, the overall reduction in the original forest stocking level is on the order of 36 percent, because of the high stocking density of pine (particularly red pine) forests. Forest cutting in

the experimental basin was completed in the late summer of 1987, and cleared areas were subsequently harrowed and planted with grass, rye, and clover. These areas will be treated initially with between 2 and 3 tons per acre of lime in the spring of 1988, and then annually with 1 ton per acre thereafter.

The purpose of the soil liming is to help establish and maintain the grass cover, since the pine stands previously growing in the cleared area have a tendency to acidify the soils through decomposition of shed needles. Grass, hay and grains prefer a more alkaline soil, whereas pine growth is not limited by soil acidity.

Data Collection

Precipitation was continuously recorded at one site in each subbasin, after weekly checks at two other sites in each basin showed that areal variation was negligible. Wet deposition chemistry samples were collected weekly at a site near New Salem, about 5 miles north of the control area, using a wet-dry deposition collecton.

Stream gaging stations were installed at three sites; one in the control basin and two in the experimental basin. All were equipped with instrumentation for continuous recording of water level. Stage - discharge rating curves have been established for each site. One gage in the experimental basin was located at an area upstream from the first, directly adjacent to an area planned for clearcutting. This gage was equipped with a water-quality minimonitor, an automated sampler and a digital data logger for regular recording of water level, temperature, pH, conductivity, and dissolved oxygen. The automated sampler was programmed to sample during storm events and the minimonitor to take more frequent readings under high flow conditions. Surface water samples at all stations were collected for chemical analysis every two weeks.

Three observation wells were installed in each basin at varying elevations and depths. All were completed to the apparent depth of bedrock, and ground water levels were measured weekly. The site/sample types were as follows: precipitation (New Salem); control and experimental ground water (3 sites each); control stream water (1 site); experimental stream water (1 downstream site and 1 upstream site). All of the sites were sampled for chemical analysis from February 1985 to present, except for the experimental upstream site, which was sampled from June 1986 to present. The precipitation site was sampled weekly by a deposition collector; the six ground water sites were sampled bimonthly by grab samples and the three stream sites, biweekly by grab samples. In addition, the experimental upstream site was also sampled by automated sampler and minimonitor electrodes at variable periods depending on water flow.

Selected water quality parameters were used at all sites: temperature, pH, specific conductance, total alkalinity, total aluminum and 14 dissolved ions: sulfate, nitrate, chloride, fluoride, bromide, calcium. magnesium, silica, ammonia - N, potassium, aluminum, iron, manganese and oxygen. Four additional parameters were measured in the stream samples: total chlorophyll a and b, dissolved organic carbon and color. Suspended solids were measured only in the experimental upstream site during high flow conditions.

All analytical work was performed by the USGS Water Quality Laboratory in Denver, with the exception of temperature, pH, dissolved oxygen and conductivity measurements, which were taken in the field, and alkalinity titrations, which were done in Boston shortly after sample collection.

In addition, borings were taken at 15 locations to help define the thickness of the till in the two subbasins.

RESULTS

Precipitation for the control and experimental subbasins prior to clearing of the experimental basin averaged 3.87 and 3.90 inches per month respectively, compared to a long-term average of 4.09 inches per month measured at New Salem. Wet deposition chemistry was characterized by the predominance of hydrogen as the major cation and sulfate and nitrate as the major anions. Hydrogen ion concentration measured as pH ranged between 3.6 and 5.0, with a median of 4.2. Sulfate concentrations ranged between 0 and 8.2 with a median of 1.9 milligrams per liter. Nitrate concentrations ranged between 0 and 2.9, with a median of 0.34 milligrams per liter.

Evapotranspiration was calculated as the sum of precipitation minus streamflow, ground water storage change, and surface water storage change. Flow in both streams was similar, ranging between 0 and 85 cubic feet per second (cfs) (median of 1.4 cfs in the control subbasin; median of 1.6 cfs in the experimental subbasin). Ground water storage change was calculated using water levels from one well in each area. Ground water contribution to streamflow was estimated using a ground water rating technique, and gains in surface water storage were estimated when this term was greater than total streamflow. Preliminary estimates of evapotranspiration indicate that this quantity is approximately 50 percent of precipitation in both areas.

Surface water chemistry in both areas gradually varied from a calcium-bicarbonate type in baseflow to a calcium-sulfate type in storm-water runoff, with little change in calcium proportions. Calcium ranged between 1.8 and 6.0 with medians of 3.8 and 2.8 milligrams per liter in the control and experimental area streamflow, respectively. Hydrogen ion concentration measured as pH ranged between 5.8 and 7.3, with medians of 6.8 and 6.7, in the control and experimental area streamflow. Alkalinity measured as calcium carbonate equivalence ranged between 1 and 18, with medians of 7 and 5 milligrams per liter in the control and experimental area streamflow. Sulfate concentrations ranged between 2.6 and 16, with medians of 6.6 and 5.4 milligrams per liter, in the control and experimental area streamflow. Nitrate was nearly always less than 0.1 milligrams per liter in streamflow in both subbasins. Aluminum ranged between 20 and 290, with medians of 40 and 60 micrograms per liter in the control and experimental areas respectively. Efforts are underway to calculate total loads of chemical constituents exported from or retained in the watershed.

The concentrations of most major dissolved constituents, except sulfate, were inversely related to discharge, decreasing in concentration with rising streamflow. Seasonally this pattern was apparent with decreasing concentra-

tions during snowmelt periods and increasing concentrations with time into the middle and latter parts of the summer as decreasing discharge, baseflow conditions prevailed. Sulfate concentrations generally increased in concentration with increasing streamflow, and decreased during baseflow conditions. The latter was especially noticeable in the experimental basin, and may be related to microbial reduction of sulfate in the wetland areas at low flows, since the experimental basin contains more wetland area than the control basin.

Ground-water levels in three wells in each sub-basin followed very similar water-level patterns, varying seasonally with annual water-level fluctuations as great as 5 feet. Ranges of concentrations for nearly all chemical constituents in the ground water were greater than those in the precipitation or surface water, with the exception of hydrogen ion and nitrate concentrations. Hydrogen ion concentration measured as pH ranged from 6.1 to 7.6, with medians at 6 wells close to 6.5. Sulfate concentrations ranged between 4.4 and 51, with medians at 6 wells between 4.9 and 17 milligrams per liter.

STATUS

Collection of baseline (pre-cutting) data is complete, and water quantity measurements and sampling were continued while forest management activities were being carried out. Forest cutting in the experimental basin and road/channel maintenance work in both basins were carried out during the winter of 1986 and spring of 1987. Cleared areas were harrowed and seeded during the late summer and the fall of 1987. Soil liming will be completed in the spring of 1988.

Baseline hydrological and water quality data is presently being reviewed and analyzed. A draft report presenting this data, along with calculations of evapotranspiration and watershed ion fluxes as a function of discharge is in preparation.

ANALYSIS AND INTERPRETATION

Preliminary interpretation of the baseline data collected through this project will consist of characterization of the aquatic chemistry and hydrological properties of the two subbasins.

Hydrological budgets will be estimated for precutting conditions. Following forest clearing, both water quantity and water quality measurements will be repeated to determine whether selective clearing of pine stands may be a viable means of increasing watershed yield, and also whether there are any measurable changes in water quality which can be attributed to the forest management work.

Of particular interest, from a chemistry standpoint, are the ion transport or retention characteristics of the watershed and its soils. Changes such as increased nitrate and basic cation export, sometimes followed by increases in hydrogen ion and aluminum levels in streams, have been observed elsewhere as a result of hardwood clearcutting. This type of change cannot be generalized or predicted with any certainty relative to pine harvesting as practiced at

Quabbin, however. The ion flux data collected during this project is also a good indication of the extent of acid rain neutralization, and the conditions under which it occurs.

Several recent studies of other Quabbin Reservoir tributaries have been conducted which include some characterization of ion transfer rates and the manner in which precipitation composition is modified in the watershed. In the interests of assessing long-term acid deposition impacts on the reservoir and its fish and wildlife habitats, there is a need to review all available data collectively to determine whether any spatial or temporal patterns can be identified or whether additional data are required for that purpose.

REPORT

Investigation of Forest Management Impacts on Watershed Hydrology and Aquatic Chemistry, Phase I (Draft Report), MDC.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Biological Monitoring Program Dickey Brook Watershed Quabbin Reservoir 1985-1986
AGENCY	Metropolitan District Commission
PROJECT MANAGER	Alfred Ferullo (former), MDC Joseph McGinn and Karen Eager, MDC
PRINCIPAL INVESTIGATOR	Gerald Smith, IEP, Inc.

OBJECTIVES

The goal of this project was to make baseline observations of aquatic biological communities in two tributary subbasins of Dickey Brook, which is located on the Prescott Peninsula of Quabbin Reservoir. These initial findings are applicable and contribute to two main areas of ongoing inquiry. One area is the effectiveness and environmental impacts of certain forest management practices designed to optimize water quality, land use considerations and watershed yield.

The second application of this study is to the growing body of information concerning the neutralization or transport of atmospheric deposition derived acids in the watersheds of Quabbin tributaries. For both of these focus areas, biological data are essential for an objective and thorough characterization of watershed processes and environmental quality. This study was conducted concurrently with an investigation of the hydrogeological properties and water chemistry of Dickey Brook by the U.S. Geological Survey.

A corollary project goal was to test the applicability of qualitative and quantitative biological sampling and analysis methods to different aquatic habitats.

METHODS

Project Site

Two tributary subbasins were selected for the project site to observe the impacts of forest management activities. The activity under consideration is that of selective clearcutting of red pine plantations and conversion of these areas to open fields. Biological data was collected for two years prior to undertaking tree harvesting in one of the subbasins (the 'experimental' subbasin). The other subbasin was designated the control watershed, in which no

forest cutting was to take place. The data from the control basin will allow any widespread changes in the hydrological budget or the deposition rates to be accounted for in comparing pre-and post cutting conditions in the experimental basin.

Two stream sampling (lotic) stations and two impoundment (lentic) stations were selected for each basin (8 total). The 8 station numbers were as follows: stream channel - control (downstream #1; upstream #3) and experimental (downstream #5; upstream #7); and impoundment - control (downstream #2; upstream #4) and experimental (downstream #6; upstream #8). Methods which allow quantitative characterization of aquatic insects, periphyton, and phytoplankton communities were employed to provide a valid basis for future comparative analyses. In addition, qualitative data on zooplankton, macrophytes and fish were obtained.

RESULTS

STREAM CHANNEL STATIONS

Aquatic Insects

Four insect orders were most frequently found at the lotic stations. The trichoptera (caddisflies) are the most diverse and abundant group for all surber samples collectively, and the diversity and abundance of this order is similar for three of the four stations. Trichoptera abundance was significantly higher at the upstream experimental basin station (#7). This station also had a notably higher proportion of Diptera (flies), and unlike the other three stations, no Ephemeroptera (mayflies) were found. In general, seasonal changes in community structure consisted of a decline in richness (number of taxa) and abundance (total density/percent composition of taxa) over the summer, due to the life cycle of the insects. This generalization is most applicable for mayflies, and is not always valid for caddisflies.

The aquatic insect communities at the sampling stations in each basin were characterized relative to each other, based on overall results of surber samples. In the control basin the downstream station (#1) had the highest abundance and diversity (richness), and the upstream station (#3) had intermediate values for both parameters. In the experimental basin the downstream station (#5) had the lowest abundance and intermediate diversity, whereas the upstream station (#7) had intermediate abundance and the lowest diversity.

Periphyton

The seasonal variation of major attached algal groups collected on glass slides was analyzed in terms of areal standard units for the two downstream tributary stations (#1, 5). Analogous data are presented for all stations for both natural and artificial substrate samples. The artificial substrate data were presumed to be more nearly quantitative and more easily standardized; however, the artificial substrate itself favors some genera over others, and may be less representative of actual richness. The areal standard unit count-

ing method may indeed be the best quantitative measure of biomass (as opposed to density of organisms) and productivity, but the natural unit ("clump") count is also useful as a qualitative indicator of seasonal changes or relative local variations.

At the control station (#1) diatoms were the most abundant algal group with peaks in August and November 1985 and lesser peaks in spring and summer 1986. The lowest abuundance of diatoms occurred in March 1986. In comparison to diatoms, the abundnace of green and blue-green algae and other species was very low. At the experimental station (#5) the diatoms were also the most abundant, but not as much as at the control station. The abundance of diatoms at the experimental station also peaked in November 1985 and April 1986 and was lowest in March 1986. Again, the green and blue-green algae were very low, as was the category of "other", except for a very large peak in April 1986 that was twice as large as the concurrent diatom peak.

The seasonal and local variation of community richness and abundance were also analyzed in natural units for all stations. Analogous data in artificial standard units for artificial substrates show fairly close agreement for qualitative seasonal changes.

Fish

Fish sampling results for the lotic habitats show that the control basin appears to support a more diverse, but less abundant fish population. Five species (blacknose dace, chain pickerel, eastern brook trout, golden shiner and tesselated darter) occurred at the control stations (#1, 3), whereas only three species (blacknose dace, golden shiner and white sucker) were at the experimental stations (#5, 7). At all of the lotic stations blacknose dace were the most abundant (144 of 153 at the experimental stations and 63 of 86 at the control stations).

IMPOUNDMENT STATIONS

Aquatic Insects

Of the two sampling methods employed, only the sweep net haul appears to be useful for insect collection from small stream impoundments and this method was practiced so as to sample the range of microhabitats present as indicated by variations in aquatic vegetation and/or water depth.

The community composition and dominant trophic relationships in the impoundments differ from those found at stream stations. Lentic habitats support organisms which are adapted to the more quiescent conditions and vegetated microhabitats; and are dominated by predators as opposed to the dominance of detritus feeders found in the streams.

Phytoplankton

Overall richness (total genera) and the range of total abundance were reported for each of the four impoundment stations, as was the seasonal variability in richness and abundance. In both the control and experimental basins

the upstream stations (#4, 8) had higher values of richness and abundance than the downstream stations (#2, 6), but the values for both control stations (#2, 4) were higher than the corresponding values for both experimental stations (#6, 8).

The richness at station #2 as greatest in late summer 1985 and again with a broader peak in late spring 1986. At station #4 the richness was greatest with two peaks in late spring and late summer 1985 and again with two similar but smaller peaks in late spring and fall 1986. Station #6 was low in late spring and peaked in early fall 1985, and again in spring 1986. All the values at station #6 were less than stations #2 or #4. Station #8 was at its highest in summer 1985 and 1986, with values about the same as those at station #6.

The overall seasonal variation at all four impoundment stations showed highest values for total genera in late spring and summer in both 1985 and 1986 and lowest values in the winter.

A breakdown of the total counts by major class provides for characterization of dominant taxa according to season and station. In the downstream control basin tributary (#2) diatoms dominated year round, and in the upstream control tributary (#4), green algae were dominant during a spring bloom, and the brown alga, Dinobryon was dominant from late summer through the fall. In the experimental basin, Dinobryon was dominant at both stations during most of the study period, except for a summer bloom of dinoflagellates at the upstream station (#8) in 1986.

The abundance (total numbers) at all four impoundment stations was low in 1985 and somewhat higher in 1986 with a large peak at station 4 in March 1986 and a lesser peak in fall 1986. Station #8 had two small peaks, one in March 1986 and a broader one in summer 1986.

Zooplankton

Representatives of five zooplankton orders were collected from impoundments over the study period. The upstream impoundments (#4, 8) in both basins supported the most abundant zooplankton populations, whereas the downstream site in the experimental basin (#6) had the lowest density and diversity of all stations. Qualitative data on zooplankton species may be valuable in detecting changes in the biological community and nutrient loads by virtue of the trophic relationships between zooplankton, algae and fish.

Macrophytes

Bur Reed was the dominant plant species at the downstream impoundments (#2, 6) in both basins. Species composition appears to be similar for both of these sites, but slightly more diverse in the control basin (#2). The upstream impoundment plants differed markedly between basins. In the control basin the upstream (#4) and downstream (#2) impoundment areas had numerous species in common, although the relative abundance patterns were dissimilar. In the experimental basin, upstream and downstream impoundments shared fewer species than in the control basin and had different patterns of species abundance. The upstream impoundment (#4, 8) appeared to support a more diverse plant community than the downstream site (#2, 6).

Fish

Here there were seven species of fish: blacknose dace, brown bullhead, chain pickerel, common shiner, golden shiner, white sucker and yellow perch. The downstream tributary impoundments both exhibited the lowest numbers and highest diversity compared to the upstream sites within each basin. Only one species, the golden shiner, was common to both basins. The qualitative differences observed between the two basins for both impoundment and channel samples suggest the need for analysis of water quality data and food availability in order to understand this variability and its significance.

STATUS

Collection of baseline (pre-cutting) data is complete and Phase II (post-cutting) data collection is scheduled to begin in Spring of 1988. Forest clearing and road/drainage channel maintenance for the experimental basin was largely carried out during the Winter of 1986 and Spring of 1989. Cleared areas were harrowed and seeded by MDC Foresters in the late Summer of 1987. Soil liming will be completed in the Spring of 1988.

ANALYSIS AND INTERPRETATION

As mentioned previously, the data generated through this project are interpretable and valuable in the context of two larger research objectives: assessment of the impacts of (1) forestry and (2) acid deposition on the aquatic environment. It is not uncommon to see overlapping of these objectives relative to other similar projects, because the physical, chemical and biological factors which may determine and/or be indicative of environmental impacts are similar.

It must be emphasized that similar research conducted elsewhere may or may not be applicable to the Quabbin or any other watershed in Massachusetts. For forestry impact assessment purposes, there can be no substitute for field investigations because the forest management practices under observation are unique to MDC watersheds. They are designed to optimize watershed land uses for the multiple purposes of increasing water yield, protecting water quality and fish and wildlife habitat, as well as continuing to harvest timber. These practices are an integral part of the MDC's ten-year plan for forest management in the Quabbin Reservoir watershed. It is hoped that this study will help to determine the degree to which these multiple goals may be served without sacrificing any one of them for the sake of the others.

For acid deposition impact/trend assessment purposes, again, there is no substitute for site specific data. The variability of these impacts with geographic location; and the mounting evidence that even watersheds within the same general area may exhibit different impacts due to local hydrogeological, morphological and biological influences, highlight the need for local investigations. Collectively, these studies will allow a better understanding of the nature of acid deposition impacts and the mechanisms by which local variables can affect them.

It is appropriate to note here the statutory and regulatory context of this research.

The legislation which created the Division of Watershed Management within the MDC mandates that the Division adopt a watershed management plan which addresses forestry, water yield enhancement, and recreational land uses (at a minimum), once every five years. The Division was also made responsible for the determination of watershed safe yield, compliance with the regulatory provisions of the water management act and protection of source water quality.

In addition, new Federal rules proposed under the 1986 amendments to the Safe Drinking Water Act call for the establishment of watershed land use control plans and programs by public water supplies providing unfiltered surface waters.

And finally, the Massachusetts Secretary of Environmental Affairs has determined that a specific Environmental Impact Report (EIR) for MDC forest management practices must be prepared, even as a generic EIR for such practices statewide is in progress.

When viewed in this context, the Dickey Brook projects represent part of a larger effort by the Commonwealth to provide a valid and logical basis from which the above planning and assessment tasks may be approached.

REPORT

Biological Monitoring Program, Dickey Brook Watershed, Quabbin Reservoir, 1985-86 (Gerald Smith, IEP, Inc.). June 1987. Available from MDC.

TERRESTRIAL EFFECTS

FORESTS

2 ABSTRACTS

TERRESTRIAL EFFECTS

FORESTS

Forest Stress Analysis - DEM

Growth of Massachusetts Forests in Relation to Potential Effects from Acid Deposition - DEM

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Forest Stress Analysis
AGENCY	Department of Environmental Management
PROJECT MANAGER	Thomas Quink, Chief Forester, DEM Boston, MA 02202
PRINCIPAL INVESTIGATORS	Gretchen Smith, William Manning, Matt Kelty University of Massachusetts, Amherst, MA 01003

OBJECTIVES

The Forest Stress analysis project was initiated in 1985 in cooperation with DEM and the University of Massachusetts. The principal objectives of this project were as follows:

1) To evaluate the extent and severity of decline problems in Massachusetts by tree species and location

2) To determine why certain tree species or forested areas are declining and what roll acid rain and associated air pollutants play in the decline process.

In 1987 additional support for the Massachusetts program was provided by The National Acid Precipitation Program to investigate red spruce and sugar maple decline. This research should substantially enhance our understanding of the biological link between pollution emissions and forest decline and help set appropriate guidelines for the protection of the forest resource in Massachusetts.

METHODS

In the first phase of the Forest Stress Analysis project, the entire state was photographed using CIR photography in order to assess the current health of the forest and establish a data base for future monitoring activities. The photographs were interpreted using a forest stress, decline, and harvest classification scheme to identify areas greater than one acre in size with dead trees, dead branches, discolored foliage, and evidence of recent removal of the dominant trees.

In the second phase, ground surveys have been initiated to investigate problem areas identified on the CIR photos and determine causal relationships. The field protocol is designed to obtain baseline information on tree condition and describe the symptomatology of the observed declines. This approach is necessary to establish cause and effect. To begin to explain a decline

problem, we must first establish that the specific symptoms of the condition are directly related to the causal factor in question, in this case acid rain. Because direct effects of acid rain have not been described for any tree species, the diagnostic procedure is essentially a process of elimination. All insect, disease, and other disturbance factors must be ruled out before a reasonable assumption can be made that acid rain is involved in the decline syndrome.

The CIR photographs identified red spruce (Picea rubens) and sugar maple (Acer saccharum) as the species of primary concern in Massachusetts. Study plots were established throughout central and western counties in a representative sample of red spruce and sugar maple stands. Additional studies were conducted on Norway Spruce (Picea abies) to provide a basis of comparison for acid rain effects studies in Europe. In order to improve the quality of the program and the applicability of the results to the Northeast region, a working relationship was established with the federally sponsored Forest Response Program and the Ministry of the Environment in Ontario and Quebec. The current status and most significant findings for each phase of the project are discussed below.

RESULTS

1. Color Infra-red Detection of Stressed, Declined, and Harvested Forests in Massachusetts

Interpretation of the CIR photos indicated that only 24,287 acres, out of a total of 3.3 million acres of forested land, show obvious signs of stress and decline based on foliar discoloration, branch dieback, and dead trees. An additional 60,270 acres show harvesting activity in the past three years, a figure that may be significant because stressed trees are often the first cut in any harvest operation. The stressed areas tend to be concentrated in a few counties (Bristol, Plymouth, Worcester, and Berkshire) rather than distributed evenly throughout the state.

On site examinations of major stressed areas identified on the CIR photographs showed that insect or disease problems could account for most of the observed symptoms. The only portion of the state so far which shows evidence of unexplained decline symptoms is in the Mt. Greylock area. Approximately 2,500 acres in this area (containing red spruce and sugar maple) has 5% of the forest canopy open because of overstory tree mortality, with some portions having 40-60% of the canopy open. Air pollution damage is definitely suspect in these areas. Many acres, however, have not been adequately ground checked. The field activities in 1987 established that the decline and mortality first noticed in the 2500-acre section on Greylock are wide spread throughout the Berkshire Hills of Western Massachusetts.

The CIR project is essentially complete although the photographs continue to be used in follow-up ground surveys. Over 10,000 copies of the photographs have been ordered by a variety of agencies involved in resource management. This project also generated 189 Mylar transparencies, showing stress, decline, and harvest area, which fit over 1:25,000 scale USGS maps. A research bulletin (#712) describing the project and containing the forest stress statistics by town and USGS quadrangle is available from the UMass Bulletin Center.

2. Forest Decline Symptoms in a Norway Spruce Plantation in Massachusetts

Three-hundred trees from a 76-year-old Norway Spruce Plantation in Colrain, Massachusetts were rated according to a health-classification scheme used in air pollution studies in West Germany. Most trees fell into the healthy or slight damage classes but 4% occurred in the moderate damage class or worse. Damage was characterized as loss of older foliage on the inner portions of the crown. These symptoms are similar to those occurring in mildly affected spruce stands in Germany for which there is some evidence that air pollution is a primary stress factor. These results provide a sound basis from which to expand the existing database on Norway Spruce decline in the Northeast and advance the development of an international research strategy on forest decline.

3. Preliminary Report on Red Spruce Decline in Massachusetts

Detailed information on mortality rates and decline symptomatology was collected from six permanent plots (20trees/plot) in Berkshire County. Field data records included tree description data, crown vigor rating, crown branch data, needle data, regeneration, and damage causal agents (physical, mechanical, abiotic, diseases, insects, unknown).

Mortality rates were high (>20 percent) in all plots, with dead trees occurring in pockets rather than scattered uniformly throughout the stand. This pattern suggests the presence of a biotic, infectious agent capable of spreading through root or branch contact. At more than one location, visible signs of root rot (Armillaria spp) were observed. Blowdowns also were common, most likely due to the shallow root and exposed site characteristics of this species.

On a large percentage of the sample trees, resinosis and swelling were visible on the main stem, and less often on the branch samples. Laboratory analyses confirmed that these symptoms were associated with infection by a trunk rot fungus (Phellinus pini) and branch canker fungus (Cytospora kunzei), respectively.

For the crown vigor classifications, defoliation was a more significant factor than crown discoloration and there were very few cases where symptoms of either type occurred on more than 50 percent of the live crowns. Needle loss occurred first on older branches in the lower crown. Although insect and disease agents contributed to crown symptoms on some trees, defoliation was most often attributed to natural shading, and discoloration to winter injury.

Undiagnosed symptoms, referred to a flecking and mottling, were visible on almost all branch samples. Both these symptoms are commonly associated with air pollution injury on other species. Regeneration was abundant on five of the six study plots. However, the same flecking and mottling symptoms were visible on the seedling foliage.

A total of nine genera of fungi were isolated from the roots of the sample trees. A significantly greater number of fungi were found to be colonizing the roots of declining trees than relatively healthy trees.

These findings demonstrate that a number of different pest problems and natural stresses are having a negative impact on the health of red spruce in Western Massachusetts. There were also a fair number of signs and symptoms of decline for which no causal agent was determined. The same sample trees will be evaluated in 1988 and 1989 to determine the progression of symptoms on the trees as the severity of damage increases over time.

4. Preliminary Report on Sugar Maple Decline in Massachusetts

A tree health questionnaire was distributed to 253 members of the Massachusetts Maple Producers Association. A follow-up ground survey was conducted at 22 sugarbushes scattered throughout Central and Western Massachusetts.

Slightly less than one-third of the respondents to the survey questionnaire felt they had a serious decline problem in their sugarlots. Acid rain was blamed for the decline by many producers, although over-mature trees, insect and disease problems, porcupine damage and road salt were also recorded.

The ground survey provided a current data base on sugar maple decline in Massachusetts. From a sample of more than 400 trees, 24 percent were rated in relatively good health, 60 percent in fair health and 16 percent in relatively poor health. The decline symptoms noted most often included the following: dead branches scattered throughout the crown, chlorotic foliage, undersized leaves and premature fall coloration. Necrotic foliage, poor taphole closure and foliage loss were noted less often.

The conditions within each sugarbush tended to be uniform. The majority of asymptomatic trees were in three sugarlots. The remaining 19 sugarbushes were in varying stages of decline.

STATUS

The aerial survey phase of the Forest Stress Analysis Project is essentially complete. Ground survey procedures, on the other hand, are still in the beginning stages and will be continued and expanded upon in the next few years. The six red spruce plots will be reexamined for pollution injury in 1988 and 1989, and eight permanent symptomatology plots will be established, four in tapped and four in untapped sugar maple stands. At each study site the soils and the soil-root interface will be evaluated for acid rain impact in order to provide a basis of comparison between soil characteristics and decline symptoms for plots and trees.

An initial scientific assessment of the relationship between acid rain and forest decline in Massachusetts will be provided after three consecutive field seasons of data collection. It should be emphasized, however, that closer to 10 consecutive years of field research are required to elucidate complex causal relationships and long-term trends. New projects to be initiated in 1988 include acid rain effects on tree reproductive processes and a survey of ozone damage to vegetation in the White Mountain National Forest. The Department of Environmental Management (DEM) has recently acquired a working sugarbush in Chesterfield, which will be available for more intensive study of plant-pollution interactions in sugar maple.

ANALYSIS AND INTERPRETATION

Based on the results of the CIR aerial survey project, only a small percentage of the forested acreage in Massachusetts is showing obvious signs of stress and decline. At a scale of 1:25,000, aerial photographs provide only a superficial look at the forest. Greater weight, therefore, should be placed on the results of the ongoing ground survey procedures.

The preliminary field results on Norway spruce, red spruce, and sugar maple clearly establish that forest decline is a significant problem for sensitive species in certain areas of Massachusetts. Mortality rates are high in the red spruce forest and sugar maples display a variety of decline symptoms. Although acid rain has not been identified yet as a principal damage agent, there is some indication that it plays a significant role in both cases. For example, a high percentage of the visible injury symptoms on red spruce needles could not be attributed to any know insect or disease pest. Severity of injury was greater on the upper needle surfaces directly exposed to pollution impact. In addition, most of the identifiable injury was cause by organisms of secondary action that don't normally invade an area unless the trees are in a weakened condition. Chronic air pollution stress might reasonably be suspect in these areas.

Some researchers have suggested that the decline and mortality in red spruce and sugar maple should be interpreted as an early warning signal of more serious effects to come. Red spruce is known to have considerably less genetic variation than that recorded for most other coniferous species. This limits its ability to adapt to relatively rapid changes in its environment such as increases in pollution loading. Similarly, sugar maple is considered to have a relatively low stress tolerance. In Quebec, where maple decline is most serious, hardwood species found in association with the sugar maple are beginning to show signs of stress and decline. We need to be concerned that if deposition continues at its current level, the injury threshold for many more species will be exceeded. Ultimately we may document these effects as increases in tree mortality or as changes in species composition in a given area.

Policy Recommendations

Three areas of activity are recommended. First, the air quality and atmospheric deposition monitoring should be improved for the large forested areas of rural Massachusetts. With respect to forest decline, we are primarily concerned with monitoring the regional pollutants ozone and acid rain. DEQE should provide the equipment and support services for precipitation and air quality monitoring at DEM's permanent field sites. A fully equipped mobile unit would provide the greatest flexibility to meet present and future research needs. At the very least acid rain and ozone data should be collected from high and low elevation sites at Mt. Greylock, and a cloud chemistry monitoring unit should be installed at the summit. It should be understood that DEQE and DEM must coordinate research activities in order to make an accurate assessment of the relationship between air quality and forest decline.

Secondly, a long-term biomonitoring program should be established to uniformly measure key forest health parameters. DEM's forest survey activities should be expanded until the baseline data on all species of concern have been collected for Massachusetts. The program also needs to support research to better define the specific variable and data collection procedures that will allow us to detect stress and interpret causal relationships. The USDA Forest Service Forest Pest Management Staff in Durham, NH is developing comprehensive procedures which will address the need for an acid rain early warning system in the Northeast. DEM should implement these procedures as soon as they are made available.

Thirdly, DEM should continue to support controlled exposure studies conducted at UMass which directly complement research activities in the field. These should include, but not be limited to, the evaluation of acid rain and ozone effects on root-fungi associations. This type of research contributes greatly to our understanding of causal relationships and may go a long way towards elucidating the mechanism(s) of acid rain damage.

Understandably, there is a certain amount of frustration and disappointment felt by policy makers and the general public that research has been unable to substantiate acid rain as the sole cause of forest decline. But this is really missing the point. Granted, the cause(s) of the problem have proven to be quite complex, but the trees, nevertheless, are declining. Rather than continuing to speculate on the relative contribution of acid rain to forest decline, we need to commit ourselves to the long-term research that is required to generate the answers we need to make intelligent, informed decisions on natural resource policy. In the meantime, scientific uncertainty should not be used as an excuse for inaction on pollution abatement.

Massachusetts would do well to follow the lead of the American Forestry Association. The AFA recently published the opinion that "...given the scientific evidence available, and the risks associated with forest resource degradation,...further emission controls of sulfur dioxides, nitrogen dioxides, hydrocarbons, ozone and toxic metals now are warranted to protect the forest ecosystem."

PUBLICATIONS

1. "Color Infrared Detection of Stressed, Declined and Harvested Forests in Massachusetts" by W. P. MacConnell, M. J. Kelty, D. Goodwin and K. Jones. Mass. Agric. Exp. Sta. Res. Bull. No. 712, Nov. 1986. 46 pp.

2. "Forest Decline Symptoms in a Norway Spruce Plantation in Massachusetts" by M.J. Kelty and T. Kyker-Snowman. In: Proc. of the Int'l Symp. on Effects of Atmos. Poll. on the Spruce-Fir Forests of the East. U.S. and FRG; Burlington, VT, Oct. 19-23, 1987.

3. "History of Land Use Practice on Spruce Stands in Berkshire County, Massachusetts" by L. Bozzuto. Aug. 1987. (unpublished document).

4. "Preliminary Report on Red Spruce Decline in Massachusetts" by G.C. Smith. In: Proc. of the Int'l Symp. on Effects of Atmos. Poll. on the Spruce-Fir Forests of the East. U.S. and FRG; Burlington, VT, Oct. 19-23, 1987.

5. "Preliminary Report on Sugar Maple Decline in Massachusetts" by G.C. Smith A Progress Report - Dec. 1987.

PRESENTATIONS

6. "Acid Rain and Sugar Maple Decline in Massachusetts" by G. C. Smith. Mass. Maple Producers Assoc., Annual Meeting, Jan. 9, 1988.

7. "Factors Producing Forest Stress" by G. C. Smith. Workshop for Technical Directors and Administrators of the Italian "Communita Montane" Nov. 10, 1987.

8. "The Impact of Acid Rain on Red Spruce on Mt. Greylock" by G. C. Smith. Appalachian Mountain Club - Interpretive Program. Oct. 13, 1987.

9. "The Massachusetts Acid Rain Research Program" by G. C. Smith. Society of American Foresters - Student Chapter. April 6, 1988.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Growth of Massachusetts Forests in Relation to Potential Effects from Acid Deposition
AGENCY	Department of Environmental Management
PROJECT MANAGER	Thomas Quink, Chief Forester, DEM Boston, MA 02202
PRINCIPAL INVESTIGATORS	Donald Mader and David Adams University of Massachusetts, Amherst, MA 01003

OBJECTIVES

Most studies of tree growth in regard to effects from acid rain and air pollution have relied on individual tree ring analysis to evaluate long-term growth trends. A more valid basis for detecting changes in growth over time may be overall volume growth of individual trees of an entire forest stand. Using this approach, white pine and red pine stands that had been measured 20-30 years earlier were remeasured to allow comparisons of recent stand growth rates with those of the previously measured periods. The primary objective was to assess any special or general changes in growth rate which might signal changes in tree vigor and indicate environmental stress not detectable by overt external symptoms.

METHODS

12 red pine and 15 white pine plots were chosen for remeasurement. Tree diameters and total heights were taken on 10 trees/plot for a height-diameter curve. A subsample of these same trees was felled and sectioned for stem analyses. In the laboratory, growth ring measurements were made on the stem sections and volume growth estimates prepared using methods analogous to those used in the earlier study. Tree volumes for the 1960s and 1980s were plotted on the same graph for comparison. In addition, height growth of the dominant and codominant trees from the two periods was checked for consistency and the change over time determined.

RESULTS

In most stands height growth over the last 20 years shows a gradual decrease. This trend might be interpreted as an indication of reduced vigor and growth. However, it is more likely that this is a normal trend reflecting a gradually reduced growth rate with increasing stand age. In any case, current height growth measurements exceed those expected for similarly aged trees growing in favorable environments.

The stand volume growth estimates show no consistent pattern with respect to volume growth changes over time. In more stands growth rates in the current period were higher or only slightly less than in the earlier growth period. Those stands where severe decreases in growth rates were observed also showed decreases in numbers of trees per acre, suggesting high mortality rates. No attempt was made to determine causal relationships.

ANALYSIS AND INTERPRETATION

The growth measurements and analyses for both red pine and white pine do not show any general, widespread pattern of decrease in growth which might be attributed to acid rain or air pollution in recent times. However, certain stands show abnormally high mortality and severe growth reductions, so site related health and decline problems which may involve acid rain or air pollution effects cannot be ruled out.

RECOMMENDATION

The pine stands showing a severe loss in volume growth should be examined more closely to determine the causes of declining vigor and the environmental factors or changes contributing to their condition. Until that work is complete, the possibility remains that the changes in growth are due to the elimination of sensitive genotypes by air pollution stress.

REPORT

"Growth of Massachusetts Forests in Relation to Potential Effects from Acid Deposition" by Donald L. Mader and David R. Adams. Progress Report February, 1987.

TERRESTRIAL EFFECTS

AGRICULTURE

3 ABSTRACTS

TERRESTRIAL EFFECTS

AGRICULTURE

Predicting Species Tolerance in Nursery Crops to Acid Precipitation/Gaseous Air Pollutant Complex using Pollen Screen - DFA

The Acid Rain-Ozone Pollution Complex and Reproductive Processing in Crop Plants - DFA

Acid Precipitation and Physiological Action of Crop Growth Regulators, Herbicides and Crop Protectants - DFA

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE — Predicting Species Tolerance in Nursery Crops to Acid Precipitation/Gaseous Air Pollutant Complex Using Pollen Screen

AGENCY — Department of Food and Agriculture

PROJECT MANAGER — Ammie Chickering, DFA
Boston, MA 02202

PRINCIPAL INVESTIGATORS — William A. Feder and Robert L. Wick
University of Massachusetts

OBJECTIVES

The objective of this research is to study the relationship between tolerance to air pollution stresses in pollen and the pollen parent and to develop from these relationships a useful technology for using pollen to screen for tolerance to air pollutant stresses among tree and woody ornamental species and cultivars. The product is to be a practical, inexpensive, rapid screening method for revealing to growers which trees and woody ornamentals are more or less tolerant to a variety of air pollutant stresses. Financial support for this Task Order became available in October 1985 and support has been extended through June 30, 1988. This report covers the period from October 1985 through October 1987.

Rationale

Earlier studies in this laboratory have shown a direct correlation between the pollen/pollutant reaction and the parent plant pollutant reaction. A plant which is sensitive to a pollutant like ozone produces pollen that is ozone-sensitive. Pollen sensitivity is reflected by the rate of tube growth in vitro under pollutant stress when compared to the same pollen tube growth rate with no pollutant stress. By exposing pollen to clean air or polluted air, and then factoring out the normal pollen growth rate, it is possible to relate pollen tube growth rate to pollutant dosage. The relative growth rate in vitro of a particular pollen population with or without pollutant stress is at once a measure of the sensitivity of the pollen and the pollen parent to a particular pollutant stress. The pollen growth rate figures provide us with a rapid laboratory screen for evaluating the relative sensitivity of plant species to a particular pollutant stress. Years of field testing can thus be reduced to a few hours in the laboratory.

METHODS

The method for pollen finger printing is as follows.

1) Pollen is extracted from flowers of the same age and suspended in liquid growth medium.

2) A small amount of pollen suspension is transferred to a filter paper disc and suction-dried.

3) The disc is placed, pollen side down, on an agar gel/growth medium, pressed gently against the agar surface and lifted from the gel. Pollen is now evenly distributed on the gel.

4) Pollen is exposed to ozone or clean air using a standard ozone dose.

5) Pollen tubes are fixed and stained with iodine solution, and tube lengths are measured.

6) Lengths are placed in classes and graphed.

7) Patterns of length distribution are compared and pollutant tolerance calculated.

RESULTS

To date, we have screened the following plant materials for tolerance to ozone: american elm, american beech linden, red maple, sugar maple, norway maple red oak, white oak, green ash, white ash, black locust, flowering crab apple, Forsythia, and several cultivars (cvs) of azalea, lilac, petunia and tobacco. (Petunia and tobacco cvs were used as background data bases for checking theory, because we had previous experience with these cvs.) The responses ranged from highly tolerant to very sensitive (little or no pollen tube growth). Tube growth of american linden was actually stimulated by exposure to ozone.

Pollen growth with and without ozone stress was quantified in the form of histograms for five lilac species and cultivars. The degree of shift to the left of the ozone histogram in comparison to the charcoal-filtered (clean) air histogram is the measure of tolerance to the applied ozone stress. The mathematical representation of these histograms yields a numerical difference between control and ozonated responses which is called the pollutant tolerance number (PTN). A high PTN reflects high tolerance, and a low PTN shows low tolerance (greater sensitivity) to a particular pollutant or pollutant mixture. PTN is the reciprocal of the measured distance between the ozone and the control curves.

Tolerance to ozone is greatest in lilac cv Primrose (PTN 0.5) The other four lilacs are listed in order of decreasing tolerance (increasing sensitivity) to ozone: cv Miss Ellen Wilmot (PTN 0.12); cv Persian Lilac, Syringia persica (PTN 0.03); Purple Lilac, Syringia vulgaris (PTN 0.028); and most sensitive, cv Montaigne (PTN 0.020). cv Montaigne is 25 times more sensitive to ozone than cv Primrose, and 1.5 times more sensitive than the common lilac, S. vulgaris.

STATUS

In addition to the lilac series used above to illustrate the process, about 100 other series, now tested and recorded, require processing. These include all of the plant materials listed earlier, and must also include as many more plant materials as time will permit in spring 1988. We hope to increase the numbers of plant materials processed by forcing plants or plant to flower in the greenhouse. The systems for obtaining, dispersing, growing and stressing the pollen are now practical and readily reproducible. The task now is to use these systems to test the responses of as many plants as possible to at least one pollutant. Further tests using other pollutants or pollutant mixtures will probably have to wait for another year of funding, but there is no question that this kind of study should be pursued.

ANALYSIS AND INTERPRETATION

The data indicate that the observed differences in tolerance (or sensitivity) to ozone are real and therefore useful for predicting sensitivity of species and cultivars to ozone and other pollutants and pollutant mixtures. By making the system "user friendly", we would hope to develop a laboratory setup that could process at least the common woody plant materials that are popular in Massachusetts. This would enable nursery operators and landscapers to select plant materials which could best adapt to local environmental situations, and thus cut losses from attempting to grow the wrong (i.e. intolerant) plants under particular stress conditions.

It is important to note that a range of tolerance to ozone was found within each tested pollen population. Current genetic studies have indicated that only about 15% of genes in pollen are unique, and the other 85% are carried by both pollen and pollen parent. This not only supports our hypothesis that the pollen can act as an indicator of pollutant sensitivity in the parent population, i.e. the whole plant, but also that the pollen can exert a marked effect on the progeny of these plants. Thus, if a pollen population shows a high percentage of tolerant pollen, the progeny of plants pollinated by that pollen will be more likely to survive exposure to that pollutant stress than the progeny of plants pollinated from a pollen population which shows a high percentage of pollutant sensitive pollen.

The long-term effect of this pollen driven diversity will be to effect changes in the loss of shade tree and forest tree populations. That this does indeed happen is illustrated by the disappearance of Ponderosa pine in Southern California under ozone stress.

A recent (November 1987) international conference on ozone trends in various regions of the U.S.A., coupled with satellite observations of ozone in the troposphere, clearly indicated that there has been no downward trend in ambient ozone levels over the past 15 years, and that there is a good possibility that troposphere ozone may blanket the U.S.A., and even the world. This means that current air quality standards and emission controls are permitting phytotoxic levels of ozone in ambient air over most of the country, including the Northeast. It follows that any plant material grown outdoors is subject to stress from this level of ambient ozone. Our work, therefore, is

not an academic exercise, but a useful tool (for the near future at least) to insure that the best, most resistant plant materials are propagated and planted.

Unless pollutant stresses are abated. we can expect to see the elimination of pollutant sensitive plants all over the world, as well as in Massachusetts. Our studies of pollen sensitivity to pollutants and of the diversity derived from this sensitivity will help us to understand which populations are at risk. This will not stop pollution, but it will give us a tool to help farmers and nursery operators make decisions in a logical manner when they plant into a polluted environment.

The generosity and foresight of the Department of Food and Agriculture (DFA) in supporting the "start-up" of this study is much appreciated. Another year of support will produce a practical list of how some of the popular, commercially grown woody plant materials perform under pollutant stress. This is our perceived "deliverable" to the Massachusetts grower.

PUBLICATIONS AND PRESENTATIONS

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Feder, W.A. and R. Wick, 1987. "Predicting species tolerance in nursery crops to acid precipitation/gaseous air pollutant complex using pollen screen". Interim Draft Report for Food and Agriculture Task Order #3, Modification 1, UM Reference No. 87A1481.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	The Acid Rain-Ozone Pollution Complex and Reproductive Processes in Crop Plants
AGENCY	Department of Food and Agriculture
PROJECT MANAGER	Ammie Chickering, DFA Boston, MA 02202
PRINCIPAL INVESTIGATORS	William A. Feder and Lyle E. Craker University of Massachusetts

OBJECTIVES

The objectives of this research were to examine the sensitivity of the reproductive process in crop species to acid rain and ozone. Sensitivity would be measured by determining the effect of the two pollutants on pollen germination and pollen growth. A reduction in pollen germination and tube growth would result in decreased crop yields, because less seed and fruit would be produced. Financial support for this Task Order (#4) became available in October 1985 and support has been extended through June 30, 1988. This report covers the period from October 1985 through October 1987.

Rationale

In order for many crop plants to reproduce and thus produce seeds and fruit, pollen must move from the stamen to the stigma within the flower allowing the egg cell in the ovary to be fertilized by the male gamete in the pollen. In crops such as corn and apples, this process occurs in the ambient environment where the entire procedure is exposed to any acid precipitation and ozone present within the environment at the time of pollination. Failure of the pollen to germinate and grow because of acid rains, ozone or a mixture or the two pollutants, would decrease crop yields. Evaluation of pollen development under simulated acid rain episodes and ozone exposure will provide an indication of the sensitivity of crops to these pollutants and enable the quantitative prediction of potential crop loss in Massachusetts from air pollution.

METHODS

The testing methods used to evaluate the effects of acid rain and ozone on pollen germination and growth are the following.

1) Pollen is collected from plant material and cleaned.

2) Agar gel growth medium is prepared at different pH levels.

3) A portion of pollen is evenly distributed across the growth medium using a specially designed pollen application apparatus.

4) The pollen on the agar gel is placed in an incubator at a fixed temperature to allow the pollen to germinate and grow.

5) Germination and tube elongation of the germinating pollen are measured and compared to pollen not under pollution stress.

6) A portion of fresh pollen is placed on stigmatic tissue previously treated with pollutant.

7) The quantity of pollen germinating and growing on stigmatic tissue is evaluated and compared to plants not treated with pollution.

8) The relation of pollution episodes to quantities of available pollen is evaluated.

RESULTS

To date, the effect of pollution has been evaluated on corn (Zea mays), apples (Malus spp.) and several types of flowers. In each case, the reproductive system has been sensitive to pollution. There were measured differences among apple varieties where pollen was tested for sensitivity to acid rain, indicating that an acid precipitation episode could reduce yields more in some varieties than in others. The effect of simulated rain on pollen in apples and corn appears to be directly related to the pH of a rain event.

Tests with corn have indicated that acid rain will affect both pollen and stigmatic tissue in the reproductive system. Corn pollen placed on an agar gel medium containing simulated acid rain shows reduced germination and tube elongation. Germination and tube elongation of corn pollen are also reduced on stigmatic tissue exposed to simulated acid rain. The number of seeds on an ear of corn is reduced when limited quantities of pollen are used in pollination of ears previously exposed to an acid rain event.

All the available evidence suggests that the reproductive systems in these crops are sensitive to pollution, and that under special circumstances where the amount of pollen in a field is reduced, a pollution episode at the time of pollination would reduce crop yields.

STATUS

Progress is continuing in the evaluation of parameters that affect pollen germination and tube elongation under pollution stress. The effects of mixtures of ozone and acid rain episodes on pollen are currently being evaluated. Results from all experiments are being prepared for publication in scientific journals and field reports for farmers. Information has been presented at several professional scientific meetings for evaluation by other scientists. Several manuscripts detailing results of the research have been published and others are in various stages of preparation.

ANALYSIS AND INTERPRETATION

The data indicate that crop and orchard yields could be reduced by pollution episodes during the time of pollination. The ultimate effect of pollution on yields appears to be related to the quantity of pollen available in the field. In normal cropping years with an abundance of available pollen, yields probably would not be reduced by pollution effects on the reproductive system. In those years, however, when dry weather or excessive temperatures or rainfall reduce the quantities of available pollen, a pollution event at the time of pollination would affect the reproductive system enough to reduce plant yields.

Obviously, the implication of the data are important to the productivity of agriculture in Massachusetts and other areas subjected to pollution episodes. The serious nature of the potential crop losses to Massachusetts farmers suggest that this study should be continued in order to inspect additional crop plants and environmental situations that could lead to further decreases in yield. The generosity and foresight of the Department of Food and Agriculture (DFA) in supporting this study is appreciated and has led to significant information related to the effects of pollution on agriculture in Massachusetts. Additional research will be necessary to determine the probable extent of crop loss and the conditions under which those losses would occur.

<u>Publications</u>

1. Craker, L.E. and P.F. Waldron. 1988. Acid rain and seed yield reductions in corn. Environ. Qual. (submitted).

2. Craker, L.E. and P.F. Waldron. 1988. The sensitivity of pollen to acid rain in several species. (manuscript in preparation).

3. Craker, L.E., P.F. Waldron and F.S. Wertheim. 1988. Acid rain, pollen germination and yield reductions in corn. Environ. Pollut. (in press).

4. Waldron, P.F. and L.E. Craker. 1987. The development of a pollen dispersal system. Environ. and Expt. Botany 27:325-328.

6. Wertheim, F.S. and L.E. Craker. 1987. Acid rain and pollen germination. Environ. Pollut. 48:165-0172.

7. Wertheim, F.S. and L.E. Craker. 1988. Effect of acid rain on corn silks and pollen germination. Journ. Environ. Qual. 17:135-138.

<u>Abstracts and Presentations at Professional Meetings</u>

1. Craker, L.E. 1986. Acid rain and pollen development. 18th Annual Air Pollution Workshop, Chicago, IL.

2. Craker, L.E. and P.F. Waldron. 1986. Pollen number as a contributing factor to an acid rain/seed set effect in corn. Agron. Abstr. p. 92.

3. Craker, L.E., S.J. Herbert, P.F. Waldron and F.S. Wertheim. 1985. Susceptibility of reproductive process in corn to acid precipitation. Abstracts and summaries of National Acid Precipitation Assessment Program. Brookhaven National Lab., Upton, NY. p. 8.

4. Waldron, P.F. and L.E. Craker. 1986. Acid rain effects on several species on pollen. 18th Annual Air Pollution Workshop, Chicago, IL.

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7. Wertheim, F.S. and L.E. Craker. 1986. Acid precipitation and corn pollen germination on the silk. 18th Annual Air Pollution Workshop, Chicago, IL.

8. Wertheim, F.S. and L.E. Craker. 1986. Effects of acid precipitation on corn silks and pollen germination. Agron. Abstr. p. 105.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Acid Precipitation and Physiological Action of Crop Growth Regulators, Herbicides and Crop Protectants
AGENCY	Department of Food and Agriculture
PROJECT MANAGER	Ammie Chickering, DFA Boston, MA 02202
PRINCIPAL INVESTIGATOR	Lyle E. Craker University of Massachusetts

OBJECTIVES

The objectives of this research were to investigate the interaction of herbicides and acid rain effects on crop plants. Particular attention was focused on the possibility that acid rain might alter or eliminate the selectivity of herbicides, making crop plants susceptible to injury from chemical regulators intended to reduce competition from weeds. If herbicides alter susceptibility of crop plants to acid rains or if acid rains alter the activity of herbicides, the product of this research would be new recommendations for weed control with herbicides by Massachusetts farmers during episodes of acid precipitation. Financial support for this Task Order became available in October, 1985, and support has been extended through June 30, 1988. This report covers the period from October, 1985, through October, 1987.

Rationale

Production of crops in Massachusetts requires the use of herbicides and other growth regulators to control weeds and maximize plant vigor and productivity. As chemical agents, the herbicides alter physiological activity of plants, changing metabolic activities and pathways and placing the plants under stress. Plants under one stress are frequently more susceptible to a second stress. Thus, crop plants could be more susceptible to acid rain after a field has been treated with a herbicide. In addition, the selectivity of several herbicides for controlling weeds without damaging crop plants depends upon anatomical, morphological, and/or metabolic differences in the two types of plants. Acid rain episodes, which have been implicated in the deterioration of leaf wax layers, leaching of ions from leaves, and altered metabolism, could make crop plants as susceptible to herbicides as weeds, reducing crop yields and preventing the farmer from using herbicides. Completion of the objectives will indicate if any problems exist with the use of herbicides in areas subjected to acid rain.

METHODS

Testing methods used to evaluate interactions between acid rain and herbicides on plants.

1. Tomatoes were used as the test plant since they are an important crop in Massachusetts and they are very susceptible to the herbicide 2,4-D.

2. 2,4-D (2,4-dichlorophenoxyacetic acid) was used as the test herbicide as it is a frequently used herbicide in Massachusetts.

3. One set of tomatoes was treated with threshold concentrations of 2,4-D that did not produce injury, and then was treated with simulated acid rain.

4. A second set of tomatoes was treated with simulated acid rain and then treated with 2,4-D.

5. Tomatoes from both sets were examined for any evidence of injury from acid rain or herbicide. Differences in injury among the treatments would indicate changes in susceptibility to acid rain and herbicide.

6. In another set of experiments, the growth regulator NAA and radioactively labeled herbicide were used. The plants were treated as above, and then the amount and distribution of the growth regulator and herbicide within the tomato plant were evaluated.

7. If the acid rain affected herbicide penetration of tissue, differences in uptake as measured by ethylene production and radioactive label could be quantified.

8. The scientific literature on acid rain and herbicides was thoroughly searched for any articles related to interactions of acid rain and herbicides on plants. Discussions were held with other scientists at USDA, EPA, and university research laboratories to determine whether they had noticed any interactions of herbicides and acid rains.

RESULTS

To date, there have been no indications of any interactions between acid rain and herbicides. The threshold of injury for tomato plants to herbicides was not affected by subjecting the plants to simulated rain before or after herbicide application. The application of herbicide did not make tomato plants more susceptible to acid rain. Of the available reports in the literature, only one (on susceptibility of the weed velvet leaf to chlorsulfuron) has suggested an effect of acid rain on herbicide action. None of the contacts with other researchers has indicated any interaction of herbicides and acid rain episodes.

STATUS

As all experimental tests and most of the other scientific evidence indicates that there is no interaction between herbicides and acid rain, any further major experimental work and expenditures on this task has been suspended. Some minor experiments will be completed if warranted. The scientific literature will continue to be evaluated for any evidence of detrimental effects due to herbicide and acid rain interaction until the end of the budget period.

ANALYSIS AND INTERPRETATION

The available evidence suggests that acid rain does not affect the susceptibility of plants to herbicides and that application of herbicides does not make plants more susceptible to acid rain.

ACID DEPOSITION MONITORING

4 ABSTRACTS

ACID DEPOSITION MONITORING

Quabbin Summit Air Quality Monitoring Project - DEQE

Ozone Monitoring at Mt. Greylock - DEQE

Wet Deposition Chemistry and Air Quality Data Analysis Project - DEQE

Acid Deposition Mesoscale Modeling Study - DEQE

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Quabbin Summit Air Quality Monitoring Project
AGENCY	Department of Environmental Quality Engineering
PROJECT MANAGER	Donald Steele, DEQE

OBJECTIVES

The primary goal of this project was to set up several comprehensive air quality/acidic deposition monitoring sites in Massachusetts. The objective of these sites is to collect accurate data on rural background air quality and wet deposition to be used by research scientists in their investigations of the effects of acid rain and other pollutants on Massachusetts natural and man-made resources. The data collected at these sites will also provide valuable information for state and national acid rain control programs, especially in the areas of wet and dry deposition, ozone, visibility impairment and fine particle effects.

These monitoring sites provide valuable baseline information on the concentrations of air pollutants at a rural background site. Long-term monitoring efforts at the Quabbin site will provide an opportunity to evaluate the impacts of the Massachusetts acid rain control legislation. Data collected from 1985-1990 will establish conditions prior to implementation of the legislation; data collected after 1990 will provide information on the effects of the legislation on air quality at one of Massachusetts most important resources, the Quabbin Reservoir.

METHODS

The monitoring site at Quabbin Summit was established in May 1985 as one of several long-term acidic deposition research sites, which are to provide critical acidic deposition information to state, regional and national research efforts. Installation and initial operation of the site were performed by C.T. Main, Inc. under contract to DEQE. In June, 1986 DEQE assumed full operation and maintenance of the site. Additional sites are currently being set up at Mt. Greylock, Waltham and the Cape Cod National Seashore at Truro.

The Quabbin site was selected because of: its location near the Quabbin Reservoir, proximity to local air pollution sources, site elevation and accessibility for servicing and utilities. The Quabbin site is located in a rural setting and provides extremely valuable data on background levels of air pollutants that are more representative of the levels experienced by most areas in Massachusetts.

The instrumentation used for this type of study must be very sensitive to low levels of air pollution, because rural and transported air pollutant concentrations are usually quite low compared to urban air pollutant concentrat-

ions. The air pollutants and parameters measured continuously at the Quabbin Summit site and reported as one-hour mean values include: sulfur dioxide, ozone, nitric oxide, nitrogen dioxide, total oxides of nitrogen, visibility (nephelometer), wind speed, wind direction, wind direction variability, temperature, dew point, relative humidity, barometric pressure, wetness and solar radiation. Air pollutants reported as 24-hour mean values include: particulate matter (reported as PM-10), inhalable particulates (reported as PM-2.5), total suspended particulates (approximately 0-100 micron), particulate sulfates and particulate nitrates. Because numerous researchers at both the state and national levels have requested additional information from the site, additional relevant parameters will be measured at the site as funds become available.

RESULTS

No violations of the National Ambient Air Quality Standards (NAAQS) for sulfur dioxide or nitrogen dioxide were observed for the period from June, 1985 through June, 1987. The NAAQS for ozone were exceeded twice during the summer of 1985, and three times during the summer of 1986.

Ambient ozone concentrations were higher in the summer months. Episodes of high ozone during the summer months were frequently associated with episodes of high sulfate particles, the combination of which may result in unhealthful air quality in Massachusetts.

High ozone concentrations were not associated with any particular wind direction during the first year of data gathering. Unlike other pollutants, ozone is not emitted, but rather created by other pollutants that are emitted into the atmosphere. This difference tends to mask ozone's origin. Also, wind directions vary tremendously during air stagnation when elevated levels of ozone occur.

Higher concentrations of sulfur dioxide and nitrogen dioxide were associated with winds from the southwest, as were reduced visibility and higher concentrations of particulates. Additionally, there were elevated (above background) concentrations of sulfur dioxide associated with winds from the east. It is possible that these elevated concentrations come from the Boston and Worcester metropolitan areas.

Elevated concentrations of sulfate particulates and low visibility days (less than 20 km or about 12.5 miles) occurred more frequently in the summer than in the winter.

Concentrations of sulfur dioxide, nitric oxide, nitrogen dioxide, and other oxides of nitrogen were higher in the winter than in the summer.

STATUS

Other efforts for this project include expanding the network with additional sites located at Mt. Greylock, Waltham, and Truro. Ozone data have been collected at Mt. Greylock during 1986 and 1987 (results are presented in another abstract). Air quality and wet deposition collection will be added to

Mt. Greylock. Ozone monitoring capabilities have been incorporated into the existing wet deposition monitoring sites at Waltham and Truro. Additional equipment will be added during the spring of 1988.

ANALYSIS AND INTERPRETATION

A network of comprehensive air quality/acidic deposition monitoring sites is being established throughout Massachusetts. The Quabbin Summit Site has been in operation for over two years and provides one of the most comprehensive air quality/acidic deposition databases in New England (analysis of these and other data are being performed in another project). The data collected for this project are available for use by university, state, and federal investigators. The Legislature has recognized the importance of the long-term acid deposition and air pollution monitoring effort being conducted by this program and has funded, through another line item, a major upgrading of the sites at Mt. Greylock, Waltham, and Truro. These funds have been provided to DEQE's Division of Air Quality Control to continue the efforts initiated in this project.

RECOMMENDATIONS

Because of the difficulty of analyzing air quality data collected for only a short period of time (two years), it is important that this site continue operating until a sufficient database exists to be able to determine patterns. The long-term database provides a foundation to evaluate changes in acidic deposition and air quality in Massachusetts over time. The upgraded network will provide invaluable additional information on air quality/acid deposition at key resources located at Mount Greylock, the State Agricultural Experiment Station at Waltham, and the Cape Cod National Seashore at Truro. Effects of acidic deposition in different areas of the Commonwealth can be more completely evaluated using data from the upgraded network. The data and summaries provided by the data analysis project from the Quabbin Summit Site should be published and distributed to researchers interested in terrestrial, aquatic and material effects in order to aid in further study of the effects of acidic deposition on these resources.

REPORT

Massachusetts DEQE - Acid Deposition Air Quaility Monitoring Program, Quabbin Summit Site, June 1985 - May 1986. Final Summary Report prepared by Chas. T. Main, Inc. (Boston, MA) for Department of Environmental Quality Engineering, October 1986.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Ozone Monitoring at Mt. Greylock
AGENCY	Department of Environmental Quality Engineering
PROJECT MANAGER	William Alsop Office of Research and Standards Department of Environmental Quality Engineering
PRINCIPAL INVESTIGATOR	William Manning, University of Massachusetts

OBJECTIVES

The Mt. Greylock ozone monitoring project was initiated by the University of Massachusetts, the Department of Environmental Management (DEM) and the Department of Environmental Quality Engineering (DEQE) early in 1986. The principal objective of establishing this project was to obtain high elevation rural ozone data near the area where forest decline had been reported. Such data were sparse in North America and not available for western Massachusetts. The Mt. Greylock site was established in order to provide a database for future rural air quality trend evaluations on high elevation forests in the Berkshires, and to assist in the determination of potential impacts of air pollution on high elevation vegetation, especially red spruce (Picea rubens) and sugar maple (Acer saccharum), both of which are in a state of decline.

METHODS

Ozone monitoring was begun near the summit of Mt. Greylock (3640 ft.) in late June 1986 and continued through mid-September 1986. A second round of continuous monitoring was done from June through September in 1987. In addition to instrument monitoring, biological effects of ozone were determined by assessing foliar ozone injury symptoms on plants of tobacco (Nicotiana tabacum), cultivars Bel-W3 (ozone sensitive) and Bel-B (ozone tolerant), grown on the summit near the ozone monitor. (A dose of 0.05 ppm ozone for three hours, under suitable environmental conditions, is sufficient to cause injury on Bel-W3 tobacco.)

1986: A Dasibi 10003AH ozone monitor and strip chart recorder were located in a DEM garage at the summit of Mt. Greylock in June of 1986. Monitoring was initiated in June and continued until 19 September. Lightning damage to the monitor and loss of electrical power on several occasions caused severe gaps in the data. These problems were solved by the end of the season.

The monitoring site was visited twice weekly to check the monitor for control and frequency accuracy. A dedicated Dasibi 10008PC monitor was used to calibrate the 10003AH monitor. Monitoring strip charts were evaluated and

average hourly ozone concentrations were determined for each hour of every day monitored. Concentrations of ozone from 0 to 0.029 ppm were considered to be background values. For this reason, only hourly ozone averages of 0.03 ppm and above were included in subsequent reports.

In June, Bel-W3 and Bel-B tobacco in plant pots were transported from greenhouse chambers to the monitoring site at Mt. Greylock. The pots were sunk into the ground up to their rims. Subsequently, each leaf of each tobacco plant was evaluated for visual symptoms of ozone injury. Injury was expressed as percent (%) of leaf area affected. Plants were replaced every four weeks.

1987: The same methods and procedures used during 1986 were used again in 1987. An important change in the program was the addition of quality assurance audits by DEQE for the Dasibi ozone monitor.

RESULTS

Significant results were achieved in 1986 and 1987. Ozone was monitored on Mt. Greylock for the first time at a rural high elevation site in Massachusetts. Elevated zone concentrations were frequently monitored, with peaks occurring between noon and midnight.

Table 1 compares Mt. Greylock ozone information for 1986 and 1987. Much more continuous data were recorded in 1987 than in 1986. The information presented in Table 1 shows that higher concentrations of ozone (above 0.08 ppm) were more frequent in 1986 than 1987, but more "above" background conditions (greater than 0.030 ppm) were recorded in 1987 than in 1986. This may in part be an artifact of the amount of monitoring conducted during 1986 and 1987, although this cannot totally explain the differences between the two years.

The previous national standard for ozone was 0.08 ppm ozone for one hour. During 1986 a total of 36 hours were recorded which had concentrations of ozone equal to 0.08 ppm or greater. During 1987 ozone concentrations reached 0.08 ppm or greater twelve times. Also, no ozone values above 0.100 ppm were recorded in 1987, whereas in 1986 seven hours equaled or exceeded 0.100 ppm. In addition, the current one hour ozone standard of 0.120 ppm was likely exceeded during 1986. However, since the monitor was set to read values between 0.00 - 0.100 ppm, it is impossible to say whether the national standard for ozone was exceeded.

Despite problems with wind, slugs and early frosts, tobacco plants were useful for biomonitoring ozone. Bel-W3 showed typical severe ozone injury each week during 1986. Bel-B showed occasional slight injury with substantial injury occurring only in July during a 2-day episode when 0.10 ppm was recorded and exceeded. During 1987 problems with rabbits and an early frost reduced biomonitoring activities. Both Bel-W3 and Bel-B tobacco plants showed similar conditions of stress as during 1986, but all symptoms were less intense than those observed in 1986.

Because tobacco is an annual herb that must be replaced every 4-6 weeks during the growing season, research was initiated to evaluate native perennial plants as substitutes. Native elderberry (Sambucus canadensis), raspberry and blackberry (Rubus spp.) and white birch (Betula papyrifera) appear to be good candidates and are being investigated.

ANALYSIS AND INTERPRETATION

Mt. Greylock is frequently fumigated by elevated concentrations of ozone, because of the altitude of the mountain, the prevailing wind patterns, and the long-range transport of pollutants that cause ozone. Other ozone monitoring studies at High Point Mountain, New Jersey and Whiteface Mountain, New York have also shown increased ozone concentrations at high altitudes, especially above the nocturnal inversion layer.

Unlike other air quality monitoring studies, the study at Mt. Greylock included ozone-sensitive and ozone-tolerant tobacco plants. Continuous occurrence of ozone injury on the sensitive Bel-W3 plants indicates that conditions are generally favorable for ozone injury when concentrations reach or exceed 0.05 ppm. This concentration, which is frequently reached and exceeded on Mt. Greylock, is much lower than the previous or current national standards that are supposed to be protective of the public health and welfare. Injury on the tolerant Bel-B plants confirms the occurrence of ozone concentrations higher than 0.05 ppm. The development of biomonitoring by appropriate perennial plants will generate future data on cumulative growth effects.

Comparison of the data obtained in 1986 and 1987 illustrates why data must be collected over a multiple-year period. Peaks of ozone were higher and more frequent in 1986 than in 1987. It is difficult to determine which, if either, of these two years is characteristic of conditions in Massachusetts. More than five years of data need to be obtained before any trends can be determined.

RECOMMENDATIONS

Mt. Greylock provides a valuable window on the general air quality picture in Massachusetts and the region. Continued monitoring at this site will generate the data base necessary to determine long-term trends and changes in air quality; until recently these data have been completely lacking.

DEQE should give a high priority to this program that is designed to enhance the air quality/acidic deposition monitoring on Mt. Greylock. This enhancement can be accomplished by upgrading the Mt. Greylock monitoring site with equipment similar to that located at the Quabbin Summit comprehensive monitoring site. In addition, monitoring of cloudwater and fog at the summit of Mt. Greylock should commence as soon as possible. Research on the chemistry of clouds and fog indicates that they contain approximately ten times the hydrogen concentration of rainwater, and thus may be a large component of acidic deposition at high elevations. Future monitoring results should be closely examined by scientists doing research on forest decline in the Berkshire region of Massachusetts in order to correlate ambient air pollution levels with observed symptoms of forest decline.

Table 1. Percent of monthly recorded hours of ozone concentration equal to or greater than sensitive vegetation damage thresholds (background concentrations < 0.03 ppm ozone, threshold injury ≥ 0.05 ppm, moderate injury ≥0.08 ppm and extensive injury ≥0.10 ppm).

	1986					1987				
Month	**Hours**	≥0.03	≥0.05	≥0.08	≥0.10	**Hours**	≥0.03	≥0.05	≥0.08	≥0.10
June	168	28	9	4	0	488	97	31	1	0
July	511	58	24	5	1	634	82	38	1	0
August	486	80	29	1	0	733	69	28	0.5	0
Sept.	444	65	18	1	0	709	53	9	0	0
Total Hours	1609					**Total Hours** 2564				

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Wet Deposition Chemistry and Air Quality Data Analysis Project
AGENCY	Department of Environmental Quality Engineering
PROJECT MANAGER	William Alsop Office of Research and Standards Department of Environmental Quality Engineering
PRINCIPAL INVESTIGATOR	Michael Sutherland, Director Statistical Consulting Center University of Massachusetts

OBJECTIVES

Acidic deposition is composed of wet and dry components. The wet components include acidic rain (and snow), acidic fog, and several other forms of acidic precipitation. Dry components consist of acidic gases and acidic particles which adhere or adsorb to natural and man-made surfaces. In order to understand the effects of acidic deposition on the resources of Massachusetts, it is necessary to know how much acidic deposition (dry and wet) is falling, where it is falling, and when it is falling. Therefore, one of the most important activities of the Massachusetts Acid Deposition Research Program has been the collection and analysis of reliable, accurate, and precise data on wet deposition (acid rain) and air quality data (dry deposition).

The primary objective of this analysis project is to summarize and interpret the large quantities of acidic deposition data that have been collected in Massachusetts since 1982. Another objective is to develop a protocol for summarizing the data from the comprehensive air quality/acidic deposition monitoring sites located across Massachusetts. The third objective, and the most difficult, is to develop a mechanism to link wet deposition data with air quality data (as a measure of dry deposition) and determine total acidic deposition.

METHODS

There are three National Atmospheric Deposition Program (NADP) precipitation monitoring sites located in Massachusetts. These sites are among more than two hundred sites located throughout the United States. Chemical analyses of precipitation samples from these sites are conducted at a central analytical laboratory contracted by the NADP. The Massachusetts sites are located within the Quabbin Reservoir watershed, at the University of Massachusetts State Agricultural Experiment Station located in Waltham, and on the Cape Cod National Seashore at Truro. Data have been collected on a weekly basis at

these sites since early winter 1982. NADP has provided summary information on the chemistry of the weekly samples for these sites through July 1987. No comprehensive analyses have been performed on the Massachusetts data, to date.

DEQE established the first of several comprehensive air quality/acid deposition monitoring sites at Quabbin Summit. This site has been in operation since May, 1985. More than two years of air quality data have been collected at the site. Additional comprehensive sites are being constructed in other critical resource research areas (the Mt. Greylock state forest, the Cape Cod National Seashore, and the State Agricultural Experiment Station in Waltham).

Data analysis for this project focuses on the wet deposition data from the three NADP sites; air quality data from the Quabbin site, the Mt. Greylock site, and the Truro site; and additional data provided by other research activities. The analyses were conducted by DEQE staff and the Statistical Consulting Center at the University of Massachusetts. Models used to estimate dry deposition amounts were provided to DEQE by scientists from the Oak Ridge National Laboratory, Tennessee.

WET DEPOSITION

RESULTS

The data from the NADP wet deposition sites at Quabbin, Waltham, and Truro have been analyzed for differences and similarities in precipitation chemistry. Distinct differences were found between the sites for the deposition and concentration of the major components of acid precipitation for the period 1982 - 1986 (See Table 1, concentration data not shown). Non-acidifying (neutralizing) contaminants in precipitation also showed distinct differences between sites over the same period of time. For the five year period of record, differences from year to year and from season to season in the concentration and deposition of most acidifying and non-acidifying contaminants were evident at the three sites.

Attempts were made to investigate similarities and differences among the NADP sites in Massachusetts for the several years of record. Annual deposition values for all the constituents of precipitation were calculated, and data for sulfate, nitrate and hydrogen ion deposition (measured at each site) are presented in Table 1. All three sites are designed to collect precipitation samples each and every week during the course of a year. In practice, this is not necessarily the case. Sampler malfunction, sample contamination, or sample loss in transit are just three explanations for missing data. As a result, each site may have a different number of total observations for a given year.

Summing the weekly values of deposition obtained at a site will generate the "observed" values (Table 1) that represent the actual amount measured in the year at each site. In order to compare yearly deposition at the three sites, the observed data were corrected to account for the missing weeks. One method used to accomplish this was substituting weekly average deposition for the missing weekly data. The results of this substitution are also presented in Table 1 in the column labeled "calculated". All sites thus have the same number of weeks of data and can be compared.

Hydrogen ion deposition provides a measure of the total amount of acid deposited at a site. Hydrogen ion deposition was greatest at the Quabbin site, less at the Truro site, and least at the Waltham site for four of the five years. In 1984, hydrogen ion deposition was greater at the Waltham site than at the Truro site.

For the five years of data available, deposition of nitrate was highest at the Quabbin site. In 1982 and 1983, nitrate deposition was greater at the Truro site than at the Waltham site, but from 1984 through 1986, deposition of nitrate at the Waltham site was greater than or equal to nitrate deposition at the Truro site.

In 1982 and 1983, sulfate deposition at the Truro site was equal to or greater than sulfate deposition at Quabbin. Generally speaking, sulfate deposition at these sites was greater than sulfate deposition at Waltham, except for 1984 through 1986, when sulfate deposition at the Waltham site appeared to be equal to, or greater than sulfate deposition at the Truro site. Since sulfate is a major component of sea salt, and some portion of the total deposition of sulfate can be attributed to sea salt (10-20%). This contribution is especially important at the Truro site which is virtually surrounded by ocean and will be accounted for in future evaluations.

The Truro site, located on the Cape Cod National Seashore, receives greater input of sea salt than Waltham and Quabbin which are not significantly influenced by sea salt inputs. Evidence of this is provided by deposition of both sodium and chloride (from sea salt) which are much higher at the Truro site than either the Waltham or Quabbin sites. As would be expected, deposition of sodium and chloride are higher, in general, at the Waltham site than at the Quabbin site located further inland.

Seasonal cycles were most pronounced in sulfate and nitrate deposition data. The highest levels of average weekly sulfate and nitrate deposition were observed during the summer and the lowest levels were observed in winter. (Figures 1 and 2). Variability of both sulfate and nitrate concentration and deposition differed across seasons at each site. Winter storms showed less variability from storm to storm than summer storms which tended to be quite variable. In Figure 2 the average weekly deposition of nitrate at Quabbin during the summer of 1984 was very high. During this period, the concentration of nitrate was lower than usual, but because of the extremely large amounts of rainfall (13.3 inches at Quabbin during May alone), high nitrate deposition was recorded. This is a good example of how a relatively rare large storm or series of storms can result in unusually high acid deposition.

Further analyses were undertaken to investigate the relationships among the sites. Correlations between the sites were examined to determine if changes at one site were accompanied by similar changes at either or both of the other two sites. For example, if it rains at one site, is it also raining at the other sites, and are the rainfall and acidic deposition amounts similar? Rainfall at Quabbin was more closely related to rainfall at Waltham than to rainfall at Truro. Similarly, rainfall at Truro was more closely related to rainfall at Waltham than to rainfall at Quabbin.

In general, the correlations for any particular ion were stronger between Quabbin and Waltham than between either Quabbin and Truro or Waltham and

Truro. The concentrations of ions in precipitation would track at Quabbin and Waltham, but not necessarily at Truro. Also the overall patterns over time for Quabbin and Waltham were similar, but different for Truro. Typically, the ionic similarities between Quabbin and Truro were the weakest. It appears that precipitation falling on Truro may be chemically different from precipitation at the other two sites.

Some ions appeared to be equally correlated between the sites. Sulfate, nitrate and laboratory and field hydrogen ions appeared to be well correlated. Ions usually associated with sea salt (sodium, chloride, magnesium and potassium) showed a high correlation between Quabbin and Waltham. Weak correlations occurred between Waltham and Truro, and no correlations between Truro and Quabbin. This pattern supports the observation that the Truro site is influenced more by sea salt contributions than either Waltham or Quabbin (which shows very little sea salt influence).

Additional within site correlations were made to determine how ions varied from week to week. Results indicated that there were two groups of ions that were highly correlated at all three NADP sites. One group consisted of sodium, chloride, and magnesium which were considered to be indicative of the sea salt influence on precipitation chemistry. Potassium was also clearly associated with this group at Truro, and hence is included as an ion indicative of ocean spray. It was less strongly correlated with the other ions at Waltham, and not correlated with either sodium or chloride at the Quabbin site. The second group consisted of sulfate, nitrate, ammonia, and hydrogen ions. These ions were highly correlated at all sites, except at Waltham, where field hydrogen ion concentration was not well correlated with ammonium ion concentration. This difference needs further investigation.

ANALYSIS AND INTERPRETATION

The analyses presented here represent the initial efforts to characterize wet deposition patterns in Massachusetts. Preliminary results indicated geographical differences among the Massachusetts NADP sites. The deposition of ions in precipitation at the Quabbin site located in central Massachusetts more closely resembled that of Waltham than that of Truro. One explanation may be the distance between the sites. Waltham is located between the Quabbin site and the Truro site.

This evaluation of the data gathered at the three Massachusetts NADP sites indicated several important patterns. Seasonal cycles were observed at all sites in sulfate and nitrate deposition, with higher deposition of both ions during the summer. Sodium and chloride were highly correlated at all sites and considered to be indicator ions for sea salt. Similarly, sulfate and nitrate were highly correlated with each other and with hydrogen ions.

Sulfate and nitrate are secondary products of fossil fuel combustion, and one would expect them to be correlated. In a similar manner, sulfate and nitrate make up most of the negatively charged ions found in wet deposition, and hydrogen is the major positively charged ion (on an equivalent basis) in wet deposition. It is, therefore, not surprising that they would increase and decrease as a group.

Sulfate from sea salt may be an important component of sulfate deposition at coastal sites, but sea salt effects decrease rapidly away from the coast. Sodium and chloride deposition at the Truro site were higher than at the Waltham site, which were higher than at the Quabbin site.

Most acidic deposition occurs during the summer months. Acidic deposition is dominated each year by roughly ten to twelve weeks containing storms which contribute 40-60% of the total acidic deposition.

Examination of the data indicates a large amount of year to year variability in deposition occurring at each site. Similarly, the data indicate that there are differences in the concentrations and levels of deposition at all sites. This makes it difficult to determine whether deposition or concentration is worse at one site compared with another.

Although patterns of deposition and concentration have been observed, it is not possible to unequivocally specify either spatial or temporal trends at this point in the analysis project. At least ten years of relatively complete weekly data will be necessary to provide "definitive" spatial and temporal trends.

AIR QUALITY

METHODS

The analyses undertaken for this aspect of the project rely on data collected by other projects funded by the Acid Deposition Research Program. Extensive air quality monitoring has been conducted at the Quabbin Summit Site since May, 1985. More recently, ozone monitoring has been added to the Mount Greylock Site beginning in June, 1986 and to the Truro Site beginning in June, 1987.

Additional air quality and precipitation monitoring capabilities will be added to the Mt. Greylock site and to the NADP sites at Waltham and Truro as part of a Division of Air Quality Control program to continue and improve the efforts initiated by the Acid Deposition Research Program.

In order to compare ozone data collected at different sites in Massachusetts over the course of several years, some method of summarizing the hourly data was required. Violations of the National Ambient Air Quality Standard (NAAQS) of 120 ppb in one hour do not present an accurate picture because effects on vegetation could be observed at lower levels. For example, as described in another project, some varieties of tobacco and other vegetation are sensitive to ozone concentrations of 50 ppb for three hours. An initial screening of the data indicated that using a four hour exposure at 40 ppb ozone as the criterion would not provide the large reduction in the amounts of data necessary to provide a evaluation of possible effects. After further screening, a one-hour exposure to 80 ppb was chosen. This exposure was the previous NAAQS for ozone.

RESULTS

A summary table (Table 2) has been prepared using the initial screening criterion of an 80 ppb ozone exposure for one hour. Data have been collected from the Quabbin site for three years, from the Mt. Greylock site during 1986 and 1987, and from the Truro site during the summer of 1987. At the Quabbin site in 1986 there were fewer hours(75) with ozone levels at or above 80 ppb than in either 1985 (95) or 1987 (97). The data indicate that the Quabbin site had more hours of high ozone concentration, as measured by the 80 ppb cutoff, than the Mount Greylock site during the summers of 1986 and 1987. During 1987 the Truro site had more hours of high ozone exposure than the Mt. Greylock site, but fewer hours than the Quabbin site. It also appears that August was a time of high ozone exposure at Mount Greylock in 1986, but not in 1987.

During the period from June to August, no one month stands out as particularly subject to frequent elevated levels of ozone. Month to month variability is particularly dramatic, and year to year total hours greater than 80 ppb also differ widely at both Quabbin and Mt. Greylock (e.g. 95, 75 and 97 at Quabbin in 1985, 1986 and 1987, respectively). This would be expected from the very different weather patterns which occurred during 1985-1987. There is some indication that Mt. Greylock has, on average, fewer elevated levels of ozone than Quabbin (more years of data are needed to confirm this). The number of ozone episodes with concentrations greater than 80 ppb that occur at Mt. Greylock and Quabbin are independent of one another. In a similar manner, the data in Table 2 indicate that the number of high ozone hours at Truro does not appear to be related to either Quabbin or Mt. Greylock.

A typical example of changes in the concentration of ozone with time of day occurred in August, 1985 at Quabbin. As is typical of summer months, there is a definite daily cycle to ozone concentration. The concentrations are low in the morning, increasing to a late afternoon plateau that on average is maintained until well into the night. The concentrations of ozone on a given day can be very different. Comparison of the day to day ozone variations in August 1985 with those in August 1987 show similarities between days, although large differences develop in the latter hours of the day.

In August 1987 the rise in ozone concentration following an early morning dip was quite steep. Ozone data for May 1986 showed a similar trend, but not as rapid an increase after the early morning low. In contrast to August, the day's peak ozone concentration in May was reached later in the day and was lower. Also the day to day variability was lower than in August. Ozone levels observed in January, 1986 were much lower than those of the summer. The diurnal cycles did not have the same characteristics as seen in the May and August examples. In January there were only small fluctuations within days and very little variability between days, resulting in a generally flattened looking diurnal cycle.

ANALYSIS AND INTERPRETATION

There are only three years of data from the Quabbin site and only two summers of data from the Mt. Greylock site. Patterns within days, weeks, months, and across years are evident, however. The data indicate large differ-

ences between years at both sites. The months with the highest number of 80 ppb ozone episodes were different from year to year at both sites.

Finding patterns and structure in the data is possible and useful. Patterns within days and across a year are evident. There are not only changes in daily patterns, but also in how much variability there is from one season to another. It is not possible to determine long term differences or patterns. Short term trends can be observed, but more data are needed to evaluate the differences among years and to adequately model longer term trends.

RECOMMENDATIONS

This initial effort concentrated on episodes of ozone exposure of one hour at 80 ppb at the three Massachusetts comprehensive air quality and acid deposition monitoring sites that are being developed. This can be considered an acute ozone exposure. No analyses have been performed to determine the extent of ozone episodes at lower levels that have been shown to cause injury to sensitive plant species. Research being done at Mt. Greylock involves the use of tobacco plants that are sensitive to ozone at 50 ppb for three hours.

Mt. Greylock is the highest point in the Commonwealth, while the Quabbin site is located at a much lower elevation and the Truro site is located at sea level on the coast. No effort has been made to account for ,or investigate, the patterns of ozone exposure at different elevations or the interactions with other geographical factors.

Further analyses need to be performed to determine the pattern of ozone exposure at these sites. Seasonal patterns, as well as yearly patterns, need to be established for all sites for several levels of ozone exposure. Then comparisons can be made between sites and between months at a particular site.

These analyses have been performed primarily on ozone data from the three sites. Similar data are available from the Quabbin site for other air quality parameters. As previously mentioned, other sites are being established to monitor additional parameters at Mt. Greylock, Waltham, and Truro. The types of analysis that have been performed using the ozone data then need to be applied to the other air quality data collected at the Quabbin site. Compounds such as sulfur dioxide, oxides of nitrogen, particulate sulfate, and particulate nitrate are of great interest to researchers investigating the acidic deposition phenomenon. Techniques developed for these three sites can then be applied to other sites and parameters as they are implemented. Additionally, the relationships between pollutants should be explored further.

Finally, in order to address the potential effects of acidic deposition and related air pollutants on resources in Massachusetts, information must be obtained from other researchers concerning the concentrations or deposition levels that are of concern.

DRY DEPOSITION

The magnitude and extent of the dry deposition of acidic particles and gases are not well known. Three lines of investigation are being conducted in

Massachusetts to better understand this important phenomenon. The first method employs plastic buckets to collect dry fallout. The second method estimates acidic dry deposition by calculating the difference between the measured amount of acidic pollutants deposited in wet precipitation and the estimated sum of the amount of acidic pollutants retained by a watershed and the amount of acidic pollutants leaving the watershed. The third method involves the collection and measurement of acidic particles and gases in the atmosphere and the calculation of dry deposition based on deposition velocities (for these gases and particles) derived from meteorological conditions (surface wetness, wind velocity, temperature, solar radiation, etc.) and the type/characteristics of the surfaces (water, soil, leaves, needles, leaf area indices, vegetation, etc.) on which the acidic particles and gases are deposited.

For the most part, direct measurement of dry deposition using plastic buckets is of limited use. For instance, dry deposition measurements of acidic nitrogen compounds (nitrate and ammonium particles and ammonia, nitric acid and nitrogen oxide gases) are very difficult since nitrogen compounds readily undergo chemical transformations within the plastic buckets. More importantly, plastic buckets cannot mimic natural surfaces (e.g. leaves, grass, or water). They may be used for comparison purposes among buckets at different locations, however, and it is possible to get a very rough estimate of relative dry sulfate deposition to a plastic bucket by taking routine measurements.

Routine measurements of dry deposition to plastic buckets have been carried out by the National Atmospheric Deposition Program (NADP) for three NADP sites located in Massachusetts and for a single atmospheric monitoring site located in Woods Hole, Massachusetts (operated by the Department of Energy Environmental Measurement Laboratory). The NADP sites have recorded too few dry deposition measurements to be useful at this time to estimate dry deposition of acidic compounds to plastic buckets. The DEOE site, however, does provide useful information. Using the monthly data (July 1976 through March 1981) from the bulk collector, the wet only collector and the dry only collector, it is estimated that between 27% and 40% of the total annual sulfate deposition captured by the plastic buckets may have been derived from dry deposition.

Two comprehensive watershed research projects have attempted to estimate dry sulfate deposition. The Massachusetts Institute of Technology's study of the Bickford Reservoir, located on the southwest and west face of Wachusett Mountain, was designed to determine the potential for acidification of the reservoir and watershed. To determine this, mass balances (input-output) for sulfate and nitrate were calculated. Nitrate deposited on the watershed and reservoir was consumed by the watershed/reservoir system, and hence not considered a significant acidification factor. As part of this study, an estimate of the dry sulfate deposition was made based on the amount of wet deposited sulfate, the amount of sulfate retained in the watershed, the amount of sulfate retained by the reservoir sediments, and the amount of sulfate leaving the reservoir as groundwater and surface discharge. The estimated dry deposition of sulfate on the Bickford watershed was 40-50% of the estimated total sulfate deposited.

The second watershed study located in the Swift River watershed of the Quabbin Reservoir was conducted by the United States Geological Survey (USGS)/

Division of Water Pollution Control (DWPC). This study, set up in a similar manner to the Bickford Watershed study, estimated the the dry deposition of sulfate to the watershed to be as much as 32% of the total sulfate deposition.

The most difficult, but possibly most rewarding, study of dry deposition is being conducted research scientists from the Oak Ridge National Laboratory and DEQE using the comprehensive air quality and meteorological data from the Quabbin Summit site. The air quality data, meteorology, and local geographic conditions are currently being blended into a complex computer model developed by Oak Ridge scientists. Modified versions of the model are being run in computers in DEQE and Oak Ridge. The model is capable of calculating dry deposition of SO2, O3, NO2, HNO3 (not measured at Quabbin), acidic particles and aerosols to a variety of surfaces. Deposition can be calculated for time scales ranging from one hour to several years (providing the data are available). DEQE is concentrating on doing one hour runs, while Oak Ridge scientists are looking at monthly and seasonal time frames. The first results of this research should be available in the summer of 1988.

ANALYSIS AND INTERPRETATION

Three methods are being employed to derive estimates of dry deposition of sulfate in Massachusetts. Preliminary results from two methods have provided similar estimates of the contribution of dry deposition to the total deposition of sulfate to Massachusetts. Dry deposition, by these estimates, accounts for between 30 and 50% of the total deposition of sulfate. Further work using the model being developed by Oak Ridge will provide additional estimates of the contribution of dry deposition to total sulfate deposition in Massachusetts.

RECOMMENDATIONS

Results indicating the wet deposition of acidic compounds to Massachusetts clearly provide only a part of the information necessary to evaluate the total loading of acidic compounds to resources in Massachusetts. The research being conducted in this project will provide a better understanding of the totals. Further efforts need to be conducted to refine these methods as well as to develop them for use over Massachusetts.

Table 1. Observed (Obs.) and Calculated (Calc.) Total Annual Wet Deposition of Field H Ion (Hydrogen), Nitrate and Sulfate at the Quabbin, Truro and Waltham NADP Sites.(1)

Site	Year	Field H Ion		Nitrate Ion		Sulfate Ion	
		Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
Quabbin	1982	66.06	92.91	1348	1844	2132	2919
Quabbin	1983	49.58	71.66	1291	1767	1791	2451
Quabbin	1984	66.35	83.73	2354	2546	2566	2776
Quabbin	1985	61.14	75.74	1908	2205	2743	3169
Quabbin	1986	60.32	78.44	1530	1769	2265	2618
Truro	1982	57.96	65.52	1337	1402	2863	3038
Truro	1983	38.95	49.40	946	1200	2087	2647
Truro	1984	35.16	39.66	878	931	1882	1995
Truro	1985	49.11	62.31	1040	1287	2113	2616
Truro	1986	40.67	51.56	1026	1241	1536	1859
Waltham	1982	30.76	38.08	1054	1225	2035	2461
Waltham	1983	30.78	32.67	1066	1086	2225	2269
Waltham	1984	46.11	50.91	1046	1109	2261	2351
Waltham	1985	45.27	57.37	1376	1555	2322	2624
Waltham	1986	38.38	44.33	1183	1256	2260	2398

(1) Total annual wet deposition for each of the ions is expressed in milli grams per square meter. The observed values represent actual deposition measured at each of the NADP sites. The calculated values represent the actual observed deposition plus the weekly average deposition for those weeks where data were missing. It is a reasonable upper bound for the wet deposition that would be observed at a site if there were no missing values

Figure 1
Average Weekly Sulfate Deposition

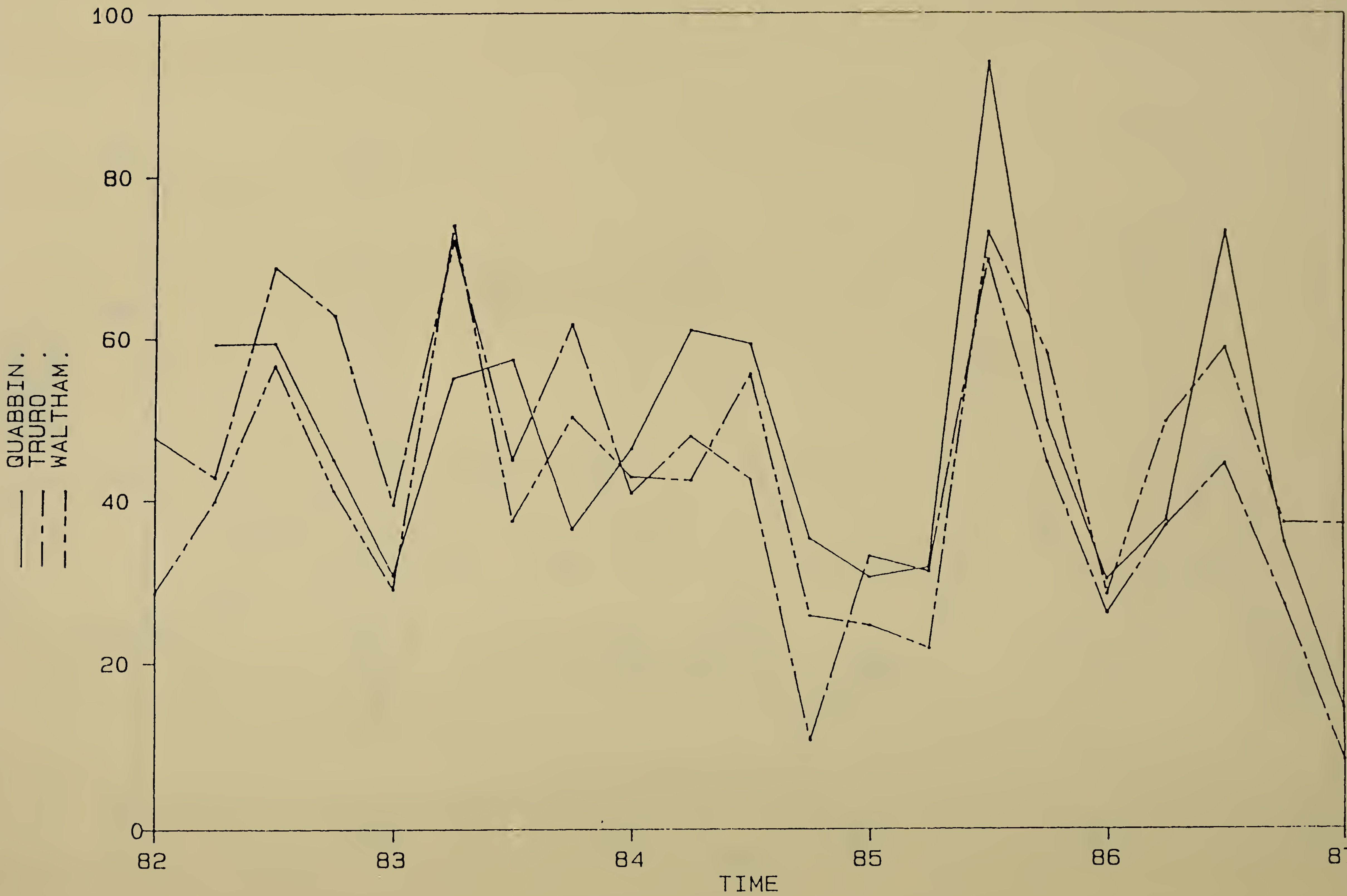

Figure 2
Average Weekly Nitrate Deposition

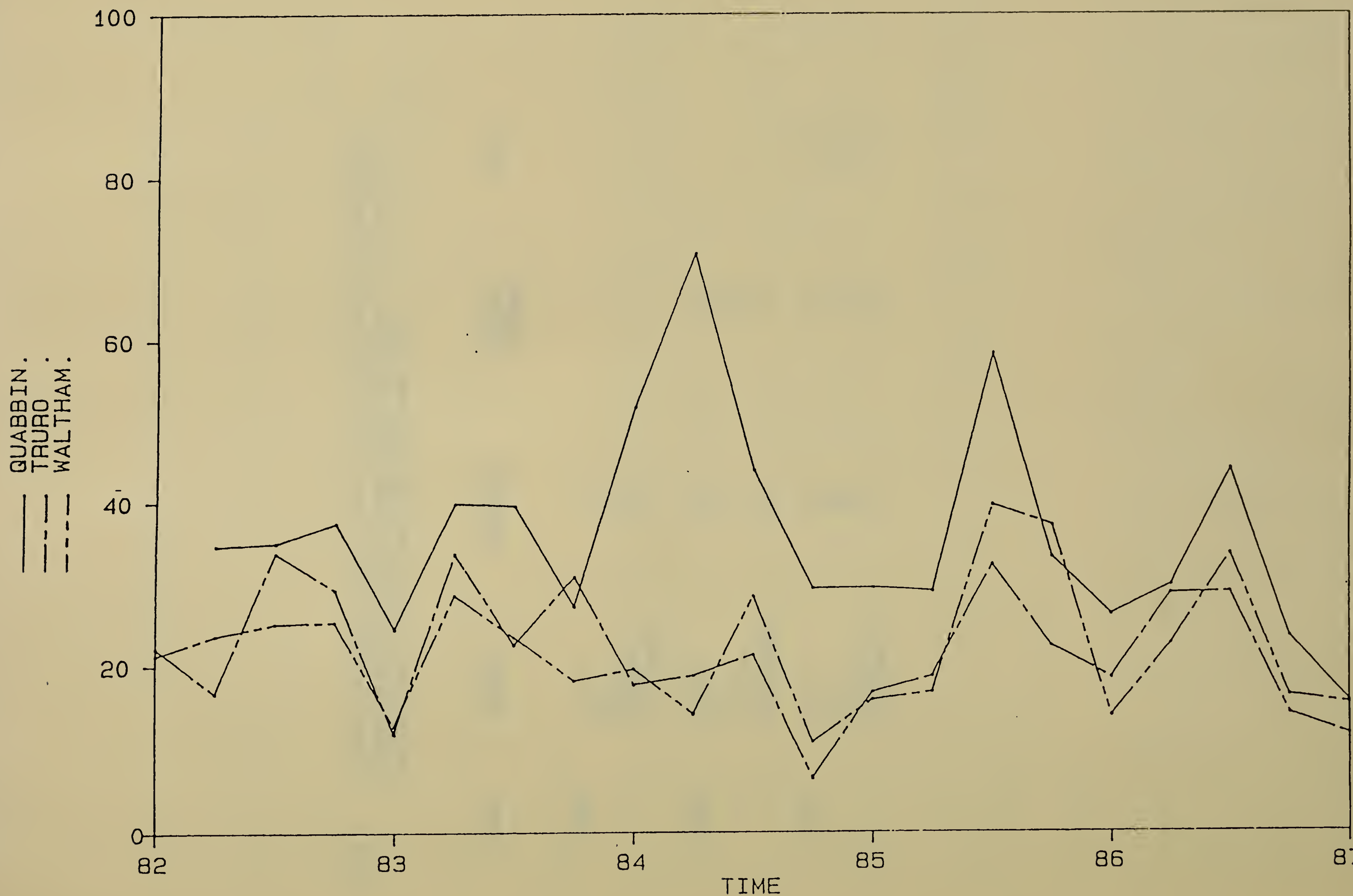

Table 2. Number of Hours With Ozone Concentration Greater Than 80 ppb Observed at the Quabbin Summit Site, the Mount Greylock Site and the Truro Site During 1985, 1986 and 1987.

Year	Month	Quabbin	Mount Greylock	Truro
1985	June	9		
	July	41		
	August	42		
	September	3		
1986	June	36	6	
	July	14	10	
	August	9	23	
	September	16	5	
1987	June	17	13	39
	July	49	2	21
	August	24	6	11
	September	7	0	0

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Acid Deposition Mesoscale Modeling Study
AGENCY	Department of Environmental Quality Engineering
PROJECT MANAGER	Daryl Grassick, Division of Air Quality Control Department of Environmental Quality Engineering
PRINCIPAL INVESTIGATOR	Joseph Scire, Sigma Research Co.

OBJECTIVES

One of the research efforts undertaken by DEQE is the investigation of the use of a mesoscale model to predict acid deposition impacts in Massachusetts which are associated with emissions of sulfur dioxide from Massachusetts sources. The model selected for this investigation - MESOPUFF II - has been used for similar studies in two other states (Maryland and Minnesota).

Mesoscale models address middle scales of atmospheric motion (domains of 10-100 miles) in which atmospheric perturbations may play a significant role in formation, transformation, and transport of air pollution. In a recent paper in the Journal of the Air Pollution Control Association entitled "Selecting Air Quality - Acid Deposition Models for Mesoscale Applications," the MESOPUFF II model algorithms were given a slight edge in technical merit over 89 other mesoscale deposition models evaluated by the authors.

MESOPUFF II includes the transformation chemistry that changes sulfur dioxide to acidic sulfate particulate and predicts the amount of sulfate in wet deposition. It is not being used to address long-range transport from out-of-state sources.

METHODS

Phase I of the modeling study was conducted between October 1985 and February 1987, and it consisted of installing, modifying, and testing the MESOPUFF II source codes at the Regent's Computer Network CDC Computer (the model was originally designed for execution on a CDC machine). Extensive data input files for 130 point and area sources reflecting over 80 percent of the sulfur dioxide emissions in Massachusetts were prepared from Division of Air Quality Control emission inventory records. A 16 by 11 receptor grid was established (20 kilometer cells) and one year of hourly surface meteorology (6 NWS stations), upper air sounding data (3 NWS stations) and hourly precipitation data (70 locations) were processed with the MESOPUFF II meteorological processing program. The MESOPUFF II model was run for a two day episode (May 8-10, 1982) in order to test the model.

In Phase II, DEQE is overseeing a contract to model the impact of sulfur dioxide emissions from 130 point and area sources in Massachusetts for a one year period of time to determine the annual pattern of deposition for 1982. Annual acid deposition contour plots will be prepared and analyzed and the findings of the study will be presented and interpreted in a report scheduled for completion in summer 1988. The Phase II Contract for the modeling study modifies the MESOPUFF II model for execution on the DEQE Microvax II computer and allows the model to simulate acid deposition impacts over a one year period of time rather than individual episodes. Results will be compared with the NADP precipitation monitoring sites to evaluate local contribution of acidity. The conversion to the DEQE Microvax II computer eliminated substantial computer costs which would have been incurred if the one year MESOPUFF II modeling run had been performed at the Regent's Computer Network (more than $300,000).

RESULTS

The test results indicated that the model produces distinct, reasonable acid deposition patterns, for individual regions in Massachusetts. The highest value of deposition for this two day test episode was 0.8 kilograms/hectare of sulfate (a hectare is approximately 2.5 acres). Deposition across the receptor grid was determined to be directly proportional to rainfall, based on the distribution of rain data and predicted wet deposition data for this episode. The results of Phase I are discussed in detail in THE DEQE report entitled "MESOSCALE MODELING STUDY: Report of One Test Episode" dated June 1987.

As of March 15, 1988, the contractor has made the necessary modifications to the MESOPUFF II programs and files. The model has been redesigned to create a "re-start" output file that contains all of the program variables necessary to continue a simulation so that annual runs rather than episode runs can be made in a piece-wise fashion on the Microvax II. A second modification was also made to efficiently execute as many sources or groups of sources as possible during off-peak hours; to allow the contribution of individual source groups to be saved for future review and investigation; and to enhance the results analysis by modifying the MESOPUFF II program to allow the production of deposition contour plots with a graphics package ($200) from the National Center for Atmospheric Research.

STATUS

The contractor is scheduled to complete all production runs for the one year modeling exercise by late April. The MESOPUFF II program will be executed to compute annual deposition impacts across the receptor grid. The contractor will prepare a draft technical report describing the methodology, results and conclusions of the annual deposition modeling results. The report will include NCAR contour plots of annual deposition for different groups of sources as well as total deposition for all sources. The report will also contain an analysis and comparison of sulfur deposition predicted by the model with available sulfate measurements in Massachusetts.

ANALYSIS AND INTERPRETATION

The initial test episode results indicated that MESOPUFF II is a useful tool for investigating source-receptor relationships, and characterizing acid deposition associated with emissions from sources located in Massachusetts. When the annual modeling runs are completed and documented, the predicted acid deposition patterns can be evaluated in conjunction with available research studies of adverse acid deposition impacts in forested areas, aquatic ecosystems, and cultural structures in Massachusetts in order to determine source-receptor relationships at receptor points of concern. MESOPUFF II will be available for further studies that could evaluate different emission scenarios and weather (other years, other emission patterns).

REPORT

"Mesoscale Modeling Study: Report of One Test Episode" prepared by D. Grassic and R. Fields, Div. Air Quality Control, DEQE, June 1987.

PUBLIC HEALTH AND CULTURAL EFFECTS

3 ABSTRACTS

PUBLIC HEALTH AND CULTURAL EFFECTS

Massachusetts Pollution Standard Index (PSI) for Air Pollutants - DEQE

Design of a Drinking Water Quality Monitoring Program - DEQE

Effects of Acidic Deposition on Cultural and Historic Resources in Massachusetts - DEQE

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Design of a Drinking Water Quality Monitoring Program
AGENCY	Department of Environmental Quality Engineering Division of Water Pollution Control
PROJECT MANAGER	Arthur Screpetis, DEQE/WPC-Westborough
PRINCIPAL INVESTIGATOR	Paul Jos. Godfrey Water Resources Research Center University of Massachusetts, Amherst, MA 01003

OBJECTIVES

The impact of acid deposition on drinking water quality has received little attention by the national acid deposition research program. Yet acid deposition may impair drinking water by depositing contaminants in surface water supplies, leaching contaminants from supply watersheds, or corroding distribution systems and consequently, dissolving contaminants into the drinking water.

The objectives of this project were:

1. Conduct an extensive review of research involving the impacts of acid rain upon drinking water quality and corrosivity.

2. Survey existing drinking water quality data within Massachusetts.

3. Develop a design for a survey of current drinking water quality allowing the development of predictive models of the relationship of raw water quality and distribution system composition with delivered water quality.

METHODS

The first two objectives were accomplished through the use of computer aided searches and other means. The fulfillment of the third objective was based on the information produced in the first two steps, and involved selection of appropriate statistical methods within a comprehensive design strategy.

RESULTS

A review of the existing literature on the impacts of acid deposition and the effect of acidic water on drinking water quality has revealed that the majority of surface water supplies in Massachusetts are vulnerable to acidification, that surface water supplies have experienced historical losses of acid

neutralizing capacity, and that the primary potential cause of acidification-related water quality degradation of household drinking water is the corrosion of water supply distribution pipes.

A comprehensive survey of Massachusetts surface waters by the Acid Rain Monitoring Project demonstrated that 62% of the surface waters are sufficiently low (< 10 ppm) in acid neutralizing capacity to be considered vulnerable; 22% are critically sensitive with less than 2 ppm of acid neutralizing capacity; and 6% are currently acidified. An independent estimate of reservoir sensitivity by the Department of Environmental Quality Engineering found 60% to have less than 10 ppm of acid neutralizing capacity.

In an analysis of historical data from 34 Massachusetts water supplies, Taylor et al. found that although there were no significant declines in pH (i.e., increases in acidity) over the past 35-40 years, 18 sources had experienced significant losses of acid neutralizing capacity. A study by de Francesco of drinking water quality data for seven towns with vulnerable reservoirs found a significant decline in the pH in the relatively short interval since 1974 for two towns, no significant change for four others, and an increase for one. Insufficient data were available prior to 1974 to determine if any changes had occurred before that date.

Twenty-two percent of the supplies studied by Taylor et al. had pH's below 6.0, i.e. below levels recommended for prevention of serious corrosion. Although none of the raw or treated water sampled in the Taylor study exceeded U.S. EPA maximum contaminant levels for metals, the delivered water at 30% of the homes sampled exceeded the maximum contaminant level for lead; 50% exceeded the level for copper and iron. The principal source of high levels of metals and other inorganic contaminants in delivered drinking water appears to be from corrosion of the distribution system and household plumbing and not from direct deposition of atmospheric pollution or leaching from reservoir watersheds. Because pH is one of the important determinants in the corrosion process, it can be inferred that increased acidification of drinking water supplies would lead to increased corrosion of water supply lines and higher concentrations of metals in delivered tap water.

In the Taylor study, typical treatment practices (filtration and chlorination) did not improve the pH of water delivered to homes, but the addition of caustic soda or other buffering material did. In those cases where the pH was raised to approximately 8.0 in the treatment process to reduce corrosion, the levels of hazardous metals were reduced below maximum contaminant levels. Previous studies of Massachusetts systems indicate that pH treatment can prevent the corrosion of metals from the distribution system.

Corrosion of materials from distribution systems is a complex phenomenon. Considerable effort has been focused on devising a simple index to indicate the corrosivity or aggressiveness of water. Two indices, the Langelier Saturation Index and the Aggressiveness Index are recommended by the U.S. EPA. Many other indices have been developed. None are completely satisfactory for Massachusetts water. Nevertheless, a statewide survey of 158 Massachusetts municipal drinking waters, using the Aggressiveness Index, found that 73% of the supplies had extremely aggressive water, 25% had moderately aggressive conditions and only 2% were not aggressive. Aggressiveness was closely correlated with pH.

Excessive metal concentrations in drinking water are not confined to public water supply systems. A major study of rural drinking water quality, the 1984 National Statistical Assessment of Rural Water Conditions, indicates that in the northeast the maximum contaminant levels for lead are exceeded in 9.6% of rural households; cadmium in 1.6%, selenium in 2%; iron in 16%, manganese in 16.9%; and mercury in 22%. No attempt was made in the study to determine the cause of excessive contaminant levels. Nearly all rural sources in Massachusetts are supplied by private wells and are regulated by local Boards of Health. For the most part, local regulation pertains only to bacteriological levels. Few towns require additional testing, and well testing data are stored in a manner that make statewide analysis impossible. Where additional testing is required, it is often done by labs certified by the state for bacteriological testing only. Retesting of private wells is rarely required. Because the available data are limited, dispersed and of uncertain quality, it is not possible to determine if groundwater acidification has occurred in Massachusetts as it has in Sweden.

These findings suggest the need for a statistically representative survey of existing drinking water quality at the household tap in order to determine the extent of any acidification-related problems, the cause, and the portion of the population most susceptible to such water quality problems. Other surveys have attempted to describe the problem but not to delineate its cause and effect relationships or provide sufficient data to determine the population affected.

To minimize collection and analytical requirements, three consecutive surveys are suggested. The first will glean supporting information from the files of the Department of Environmental Quality Engineering, U.S. Census, and town water supply files and coordinate these in compatible computerized files. The second survey will serve primarily to define the locations of different household plumbing types and add population information for a later evaluation of populations at risk. Finally, collection of tap water samples that would determine the source of any contaminants within the distribution system and collection of raw and treated water samples at the source would be done.

By accumulating all available information on water quality and distribution system characteristics before collecting samples for expensive chemical analysis, the design can be made cost-efficient. Use of volunteers, as proven effective in the Acid Rain Monitoring Project, can significantly reduce data collection costs and add an important educational element.

STATUS

This project, the design of a drinking water quality monitoring program, is now complete. The original intention of this project was to function as the first phase of an assessment of the effects of acid rain upon drinking water quality at the household tap. The second phase, actual conduct of the program designed by this project, has yet to be funded.

ANALYSIS AND INTERPRETATION

Analysis of existing water quality and its causes would be greatly facilitated if appropriate data were available. The Commonwealth is fortunate in having historical data of excellent quality from Lawrence Experiment Station, but appropriate parameters have been monitored for only the past decade. Improvements can be made in the timing and frequency of public water supply monitoring that will facilitate long-term trend analysis in the future. Greater urgency exists for improvement in the information system for private supplies as few communities have any data, quality control is questionable and statewide access is not possible. System characteristics are insufficiently defined and the characteristics of in-house plumbing is unknown. Much of this problem can be alleviated by providing appropriate guidance to the Boards of Health regarding data collection and reporting and by establishing a centralized data management facility.

The study design which was the final product of the project should be implemented as indicated by the wealth of evidence presented regarding the impacts of acid rain on drinking water quality. Water quality as it emerges from the household tap remains a concern of scientists and the public, and should be given high priority by funding agencies.

REPORT

"Design of a Drinking Water Quality Monitoring Program" by P.J. Godfrey, A. Ruby III, O.T. Zajicek, S.J. DeFrancesco, M. Sutherland, J.K. Edzwald and F. Taylor. Water Resources Research Center Pub. No. 154, University of Massachusetts/Amherst. August, 1986. (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control)

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Massachusetts Pollution Standard Index (PSI) for Air Pollutants
AGENCY	Department of Environmental Quality Engineering
PROJECT MANAGER	Alan VanArsdale, DEQE
PRINCIPAL INVESTIGATOR	Haluk Ozkaynak, Harvard University

OBJECTIVES

The overall objective of this research is to develop a revised pollution standard index (PSI) for Massachusetts which is based on the occurrence of air pollution and associated respiratory disease in Massachusetts. The revised PSI will have fine particle components that can be derived directly from visibility measurements. This index will be tested for accuracy in predicting public health problems and will also be compared to the existing PSI now in use in Massachusetts.

Background

During the 1970's the federal government developed a pollution standard index to provide the public with information about adverse health conditions of air pollution. The PSI program was universally administered by state agencies throughout the United States. In Massachusetts the Division of Air Quality Control adopted and implemented the national PSI. Current use of the national PSI in Massachusetts focuses on ozone pollution and is used during summer months.

Research in understanding the influence of air pollution on public health has identified two major deficiencies in the national PSI. First, air pollution conditions and associated public health problems vary among the states. Second, air pollutants other than those used in the original PSI have been identified as potential public health problems.

The Massachusetts Scientific Advisory Council on Acid Rain (SAC) recommended that acid rain research funds be use to develop a pollution standard index for Massachusetts based on new knowledge of local air pollution and associated public health problems. SAC recommended further that the research incorporate a fine particle/sulfate/visibility component into the pollution standard index.

METHODS

Research into the development of a Massachusetts pollution standard index has been conducted by the Harvard University Energy and Environment Policy Center (EEPC) for the Department of Environmental Quality Engineering (DEQE). The research has been done in two phases. The first phase focused on creating a scientifically appropriate method for developing a revised PSI for Massachusetts. The second phase refined the methodology and expanded the information base of the revised index to the four air pollution control regions of Massachusetts.

The first phase of this research involved determining the relationships between air pollutant concentrations and incidence of respiratory disease in the metropolitan Worcester and Boston areas. Hospital admission and discharge data for each metropolitan area were obtained for the years 1978, 1980 and 1982 from the Massachusetts Department of Public Health. Information on the incidence of particular categories of respiratory disease or other hospital admissions information (asthma, chronic lung disease, pneumonia/influenza, other respiratory and cerebrovascular) were obtained for different age classes from the data base. This information was integrated with air quality and meteorological data for Worcester and Boston.

Predictive models were developed to determine the relationships among visibility impairment, sulfate concentration in air, and coarse and fine particle concentration in air for the Boston and Worcester areas. Air pollution effects on the observed daily hospital admissions were studied using multiple and stepwise regression analysis. These findings were used to develop air pollution "effects levels" (defined as good, moderate, unhealthful, very unhealthful and hazardous) for use in the revised Massachusetts air pollution index. In this analysis, human age and seasonal factors (meteorological variables) were merged with the hospital admissions data and air pollution data for total suspended particles, fine particles, visibility impairment, nitrogen oxides, sulfur dioxide, carbon monoxide and ozone.

RESULTS

The results of this analysis (effects levels) show that for the most part, the effects levels of the revised PSI are close to those of the national PSI (Table 1). Exceptions are the following: The effects level of the 24-hr average sulfur dioxide has a threshold equal to half that of of the national PSI. For 24-hr average nitrogen dioxide, the national PSI does not have effects levels below the "very unhealthful" level. One-hr maximum ozone was not shown to have a significant effect on the incidence of respiratory disease (confounding effects apparently hid the significant relationships which have subsequently been found in research conducted under phase II). In addition, 24-hr average fine particle effects levels have been proposed for the Massachusetts interim PSI because the national PSI does not have a fine particle component.

STATUS

Phase I (Boston and Worcester areas) was completed by January 1986. Phase II (Springfield and New Bedford/Fall River areas) is ongoing with an expected completion date of June 1988.

ANALYSIS AND INTERPRETATION

The second phase of this research, which is ongoing, focuses on refining the phase I data base and incorporating air pollution and associated respiratory disease data from the New Bedford/Fall River and Springfield metropolitan areas into the phase I revised PSI. As in the first phase of this research, emphasis will again be given to incorporating a fine particle component. Once the phase II data have been merged with the phase I data, a statewide PSI will be developed. This Massachusetts PSI will then be tested for its ability to predict hospital admissions (for respiratory disease) in Massachusetts for time periods not used in the development of the index. If the predictive power of the Massachusetts PSI is scientifically acceptable, then full consideration will be given to incorporating this revised PSI into the present PSI system and the DEQE public outreach and education program. The anticipated time of this decision is late 1989.

RECOMMENDATIONS

Upon completion of this project and peer review of its results and conclusions, the Massachusetts Division of Air Quality Control should determine how it may incorporate the new PSI into its current PSI system. Subsequently, if incorporation of the new PSI is determined to be feasible and appropriate, then the Division should take steps to complete this integration.

Further efforts should be implemented by DEQE to inform the citizens of Massachusetts about the results of this project and its implications for revisions to the national PSI. Public meetings could be scheduled in different areas of the Commonwealth to provide descriptions of the revised PSI and how it should be used. DEQE should also develop a brochure that explains the study results, the revisions to the national PSI being implemented in Massachusetts, and the implications of these revisions.

Distributions of the results of this study and Massachusetts revisions to the national PSI should include federal agencies, particularly the U.S. Environmental Protection Agency (EPA) and the National Acid Precipitation Assessment Program (NAPAP). EPA will be able to use this study of individual air pollutants and morbidity to make additional evaluations of the national PSI in current use. It would also be appropriate for EPA to incorporate this information into reviews of the National Air Quality Standards (NAAQS) and into the development of future criteria documents.

REPORTS

"Development of a Health-Based Air Quality/Visibilty Index for Massachusetts, Phase I". Final Report by H. Ozkaynak, B. Burbank and J.D. Spengler submitted to A. Van Arsdale, Division of Air Quality Control, Massachusetts Department of Environmental Quality Engineering, December 1985.

"Refinement of a Health-Based Air Quality/Visibilty Index for Massachusetts, Phase II". Interim Draft Report by H. Ozkaynak, B. Burbank and J.D. Spengler

submitted to A. Van Arsdale, Division of Air Quality Control, Massachusetts Department of Environmental Quality Engineering, January, 1987.

"Refinement of a Health-Based Air Quality/Visibilty Index for Massachusetts, Phase II". Oral Progress Report by H. Ozkaynak, B. Burbank and B.H. Chang submitted to A. Van Arsdale, Division of Air Quality Control, Massachusetts Department of Environmental Quality Engineering, October, 1987.

Table 1. Comparison of "effects levels" for the national PSI and the Massachusetts interim PSI.

Effect Level	**SO_2**	**NO_2**		**O_3**	**TSP**	**FP**		**CO**	
	24hr	1hr	24hr	1hr	24hr	24hr	1hr	8hr	24hr
	ppb	ppb	ppb	ppb	ug/m^3	ug/m^3	ppm	ppm	ppm
Good									
National PSI	30	-	-	60	80	-	-	4.5	-
Interim PSI	30	140	110	-	75	49	16.6	-	5.3
Moderate									
National PSI	30	-	-	60	80	-	-	4.5	-
Interim PSI	30	140	180	-	75	49	16.6	-	5.3
Unhealthful									
National PSI	140	-	-	120	260	-	-	9.0	-
Interim PSI	70	250	-	-	260	81	30.5	-	9.6
Very Unhealthful									
National PSI	300	-	600	200	375	-	-	15	-
Interim PSI	300	600	-	-	375	(116)[a]	-	-	(15)
Hazardous									
National PSI	600	-	1200	400	625	-	-	30	-
Interim PSI	600	1200	-	-	625	(194)[a]	-	-	(30)

[a] Estimated from TSP levels assuming a scaling factor of 0.31.

ACID DEPOSITION RESEARCH PROJECT ABSTRACT

PROJECT TITLE	Effects of Acidic Deposition on Cultural and Historic Resources in Massachusetts
AGENCY	Department of Environmental Quality Engineering
PROJECT MANAGER	William Alsop Office of Research and Standards Department of Environmental Quality Engineering
PRINCIPAL INVESTIGATORS	Brona Simon, Massachusetts Historical Commission Larry Manire, Data Basics

OBJECTIVES

Many irreplaceable cultural and historic resources are located in regions of the United States that are exposed to elevated levels of acidic deposition, oxidants such as ozone, and particulate matter. The sensitivity of the various materials used in the construction of these resources to acid deposition and related air pollutants needs to be determined. Research currently being conducted by the National Acid Precipitation Assessment Program (NAPAP) focuses on developing damage functions which determine the incremental damage to materials associated with changes in air quality and acidic deposition.

Additional research must be conducted to determine the location of cultural and historic resources and the materials used in their construction. This information should be combined with research results from damage function studies and estimates of local air quality to evaluate resources at risk from acidic deposition and related air pollutants. The objective of this project is to develop a computerized database of the location and materials used in Massachusetts cultural and historic resources that may be sensitive to acidic deposition and related air pollutants. This database will be the basis for future damage assessment and mitigation activities for Massachusetts cultural and historic resources.

METHODS

The Massachusetts Historical Commission (MHC) currently has paper files containing information concerning over 100,000 cultural and historic resources in the Commonwealth. The first objective of this research was to develop a computerized information management system that would allow rapid identification of resources constructed using a particular material and the location in Massachusetts of these resources. This database should also allow the identification of all the resources in a particular town or geographic region. Following the development of this system, the second objective of the research was to enter the information from the MHC files.

RESULTS

The initial phase of this study involved the determination of DEQE and MHC data needs. Based on this information, Databasics, Inc. of Providence,, Rhode Island, was hired by DEQE to develop the Massachusetts Cultural Resource Information 1 (MACRIS). MACRIS is a set of computer programs that manage information about historic districts , buildings, burial grounds, objects and other structures. It also records the condition of the property and materials, environmental threats, uses, alterations, designations and methods of mitigation for these resources. The system provides for the entry of information into the computer, its correction and validation, and the production of a variety of reports.

Two examples of the reports that can be produced from MACRIS are the "Buildings with a Material" and the "Profile of a Geographic Area". The first report prints the MHC number, sorted by town name and by historic name or street address, for all properties containing a specified material in the roof, walls, foundation or trim. In the second report, for a particular town, area, Congressional District, Senate District, or the entire file, MACRIS will print the year of the oldest and newest property and the count and percent total in alphabetical order and ranked from high to low for resource types, object types, structure types, designation types, materials by resource type, and periods of significance.

MACRIS was installed at the Massachusetts Historical Commission, and data entry was initiated. There are 351 towns in Massachusetts and over 100,000 paper file entries at MHC. At present, resource information for 10 towns, including 4253 properties, has been entered in MACRIS. The towns entered at this time include Alford, Belchertown, Fairhaven, Fall River, Haverhill, Lee, Lowell, Peru, Pittsfield, Provincetown, and part of Peabody. These results will allow the identification of objects in any of the ten towns that use a particular material in their construction. Numbers of objects, as well as percentages, can be evaluated from this information.

ANALYSIS AND INTERPRETATION

The data that have been entered into MACRIS have not been field verified. It would not be appropriate to attempt to make use of the database at this time. Data are still being entered, and therefore, it would be difficult to make any statements concerning the distribution of sensitive resources in Massachusetts. Verification of the entries in MACRIS is one of the objectives of another project currently being initiated by DEQE. Results of this project will include reports that indicate the location of field verified objects that contain a particular material. Through other projects, DEQE will identify areas of high acidic deposition within the Commonwealth. These areas will be cross referenced with the MACRIS database in order to identify specific cultural and historic resources, as well as specific materials located in areas of high acidic deposition.

RECOMMENDATIONS

The Commonwealth should provide funding to allow MHC to conduct field research to determine the extent of damage to cultural and historic resources. Documentation of the current status of selected materials or resources could be accomplished photographically or through specific measurements. These initial efforts should be followed by routine re-evaluation to record actual changes in these resources.

Future work at DEQE and MHC will focus on mitigation strategies and techniques that can be applied to the materials classified as sensitive at the locations in Massachusetts identified by MACRIS. Work being performed for NAPAP on damage functions will quantify the sensitivity of materials to the effects of acidic deposition and related air pollutants. The MACRIS database should be made available to interested state and federal agencies. Combination of the inventory data with the damage function results will provide the basis for the development of an assessment of cultural and historic resources and materials at risk from acidic deposition. The state should provide future funding to produce this assessment. The state should also commit funding to undertake mitigation measures as appropriate, based on the determination of resources at risk and the available mitigation strategies. Estimates of the numbers of objects of a particular material will be an important factor in the determination of the cost of remediation.